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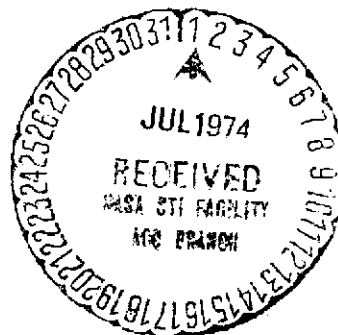
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# FINAL REPORT SYSTEM DESIGN OF THE PIONEER VENUS SPACECRAFT

## VOLUME 2 SCIENCE

By  
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ET AL.

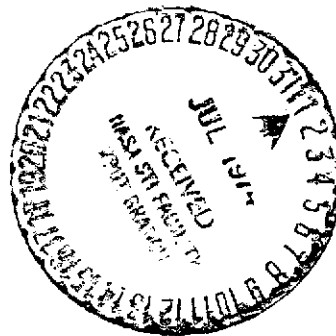
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## PREFACE

The Hughes Aircraft Company Pioneer Venus final report is based on study task reports prepared during performance of the "System Design Study of the Pioneer Spacecraft." These task reports were forwarded to Ames Research Center as they were completed during the nine months study phase. The significant results from these task reports, along with study results developed after task report publication dates, are reviewed in this final report to provide complete study documentation. Wherever appropriate, the task reports are cited by referencing a task number and Hughes report reference number. The task reports can be made available to the reader specifically interested in the details omitted in the final report for the sake of brevity.

This Pioneer Venus Study final report describes the following baseline configurations:

- "Thor/Delta Spacecraft Baseline" is the baseline presented at the midterm review on 26 February 1973.
- "Atlas/Centaur Spacecraft Baseline" is the baseline resulting from studies conducted since the midterm, but prior to receipt of the NASA execution phase RFP, and subsequent to decisions to launch both the multiprobe and orbiter missions in 1978 and use the Atlas/Centaur launch vehicle.
- "Atlas/Centaur Spacecraft Midterm Baseline" is the baseline presented at the 26 February 1973 review and is only used in the launch vehicle utilization trade study.

The use of the International System of Units (SI) followed by other units in parentheses implies that the principal measurements or calculations were made in units other than SI. The use of SI units alone implies that the principal measurements or calculations were made in SI units. All conversion factors were obtained or derived from NASA SP-7012 (1969).

The Hughes Aircraft Company final report consists of the following documents:

Volume 1 - Executive Summary - provides a summary of the major issues and decisions reached during the course of the study. A brief description of the Pioneer Venus Atlas/Centaur baseline spacecraft and probes is also presented.

Volume 2 - Science - reviews science requirements, documents the science\*peculiar trade studies and describes the Hughes approach for science implementation.

Volume 3 - Systems Analysis - documents the mission, systems, operations, ground systems, and reliability analysis conducted on the Thor/Delta baseline design.

Volume 4 - Probe Bus and Orbiter Spacecraft Vehicle Studies - presents the configuration, structure, thermal control and cabling studies for the probe bus and orbiter. Thor/Delta and Atlas/Centaur baseline descriptions are also presented.

Volume 5 - Probe Vehicle Studies - presents configuration, aerodynamic and structure studies for the large and small probes pressure vessel modules and deceleration modules. Pressure vessel module thermal control and science integration are discussed. Deceleration module heat shield, parachute and separation/despin are presented. Thor/Delta and Atlas/Centaur baseline descriptions are provided.

Volume 6 - Power Subsystem Studies

Volume 7 - Communication Subsystem Studies

Volume 8 - Command/Data Handling Subsystems Studies

Volume 9 - Altitude Control/Mechanisms Subsystem Studies

Volume 10 - Propulsion/Orbit Insertion Subsystem Studies

Volumes 6 through 10 - discuss the respective subsystems for the probe bus, probes, and orbiter. Each volume presents the subsystem requirements, trade and design studies, Thor/Delta baseline descriptions, and Atlas/Centaur baseline descriptions.

Volume 11 - Launch Vehicle Utilization - provides the comparison between the Pioneer Venus spacecraft system for the two launch vehicles, Thor/Delta and Atlas/Centaur. Cost analysis data is presented also.

Volume 12 - International Cooperation - documents Hughes suggested alternatives to implement a cooperative effort with ESRO for the orbiter mission. Recommendations were formulated prior to the deletion of international cooperation.

Volume 13 - Preliminary Development Plans - provides the development and program management plans.

Volume 14 - Test Planning Trades - documents studies conducted to determine the desirable testing approach for the Thor/Delta spacecraft system. Final Atlas/Centaur test plans are presented in Volume 13.

Volume 15 - Hughes IR&D Documentation - provides Hughes internal documents generated on independent research and development money which relates to some aspects of the Pioneer Venus program. These documents are referenced within the final report and are provided for ready access by the reader.

Data Book - presents the latest Atlas/Centaur Baseline design in an informal tabular and sketch format. The informal approach is used to provide the customer with the most current design with the final report.



## CONTENTS

	Page
1. SUMMARY	1-1
2. INTRODUCTION	2-1
3. MULTIPROBE MISSION	3-1
3.1 Science Objectives	3-1
Large Probe	3-3
Small Probes	3-3
Probe Bus	3-3
Targeting Requirements	3-5
3.2 Science Payload	3-7
Large Probe	3-9
Small Probe	3-17
Probe Bus	3-17
3.3 Tradeoff Studies	3-33
Payload Design Integration (EX2)	3-33
Experiment Window Design (PB39)	3-37
Experiments/Structure Interaction Design Study (PB29)	3-43
Externally Mounting High Altitude Sensors (EX10)	3-46
External Sensors Alignment/Stability Study (EX11)	3-59
Magnetometer Studies (EX15)	3-65
Payload Tradeoff Analysis (EX1)	3-69
Wind Velocity Measurement Study (EX8)	3-78
Experiment Integration Plan (PL10)	3-97
Probe Spacecraft/Experiment Interface Specification (SP4)	3-101
3.4 Science Payload Accommodations	3-103
Large Probe	3-103
Small Probe	3-117
Probe Bus	3-131
Additional Accommodation Considerations	3-145
Supplement 3-1: Pioneer Venus Instrument Data EXLP-3	3-149
4. ORBITER MISSION	4-1
4.1 Science Objectives and Requirements	4-1
4.2 Science Payload	4-6

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4.3	Tradeoff Studies	4-11
	Spin Axis Orientation/Science Requirements (EX12)	4-11
	1978 Orbiter Transit Trajectory Selection (MS25)	4-30
	Payload Design Integration (EX2)	4-37
	Orbiter Radio Science Impact on Communication Subsystems (CM19)	4-40
	Payload Tradeoff Analysis (EX1)	4-43
	Orbiter Spacecraft/Experiment Interface Specification (SP4)	4-46
4.4	Science Payload Accommodations	4-47
	Magnetometer	4-53
	Solar Wind Analyzer	4-60
	Electron Temperature Probe	4-60
	Neutral Mass Spectrometer	4-60
	Ion Mass Spectrometer	4-61
	UV Spectrometer	4-61
	IR Radiometer	4-61
	X Band Occultation	4-61
	Radar Altimeter	4-62
	Thermal Control Considerations	4-62
	Electrical Power	4-64
REFERENCES		R-1
APPENDIX: Science Trip Reports		A-1

## 1. SUMMARY

The objectives of the low-cost Pioneer Venus program have been established by steering groups in a series of meetings over the last few years. Information on Venus gathered by Earth-based observers and by U. S. and Soviet interplanetary fly-by and probe missions have served to define a number of problems requiring a carefully coordinated series of multiprobe and orbiter missions to resolve. The purpose of this volume is to describe the mission science requirements and demonstrate how well Hughes has succeeded in designing a spacecraft which satisfies these requirements in a cost effective way.

The Atlas/Centaur will be used to launch both the multiprobe mission (probe bus, large probe, and three small probes) and the orbiter mission, utilizing its larger payload capability to achieve a lower cost system than could be achieved with the smaller Thor/Delta launch vehicle. Both missions are currently scheduled for launch in 1978, although it is possible that one or both might slip to 1980.

Section 2 of this volume reviews the basic scientific questions about Venus. Section 3 discusses the multiprobe mission, and Section 4 the orbiter mission. Both sections are organized the same way. Science objectives are described in subsection 3.1 and the science payload in subsection 3.2, first in terms of the initial payloads defined for the Thor/Delta launch vehicle, and then the current payload for the Atlas/Centaur. The science experiments have been in the review and selection process over the period of the present study, hence nominal payloads have been specified, along with other candidate instruments.

During the study a number of specific study tasks were carried out to resolve alternative design approaches. These studies are summarized in subsection 3.3. An experiment engineering data book was compiled on all instruments to identify payload accommodation problems. In the course of gathering data on the experiments, visits were made to a large number of scientists to improve our understanding of the experiment requirements and characteristics. The resulting science trip reports are included as an appendix to this volume.

The purpose of the spacecraft and probes is to provide a suitable environment (or laboratory) for the science instruments to function in while they make observations of the planet. The purpose of the study carried out by Hughes is to design the lowest cost, technically effective equipment and laboratory. The entire study is in this sense completely science oriented. However, specific tasks related to key science instrument accommodation on the multiprobe mission include: preliminary design approaches to meet the probe window contamination problems, and to provide desired penetration of the pressure vessel

by various instruments; possible external mounting for sensors operating only at higher altitudes during probe descent; alignment and stability problems associated with the experiments; magnetic control problems and magnetometer locations; wind velocity measurement analysis for both the doppler/DLBI\* technique and the wind drift radar; and the general problems associated with the accommodation of all possible instruments.

For the orbiter mission the study tasks included: selection of spin axis orientation; choice of a transit trajectory (Type I versus Type II); identification of payload design integration problems, impact of the radio science experiments on the communications subsystems, and general problems associated with the accommodation of all possible instruments.

The accommodation of the nominal science payloads is discussed in subsection 3.4 for the multiprobe mission and subsection 4.4 for the orbiter mission, with primary focus on the Atlas/Centaur payload. Table 1-1 and 1-2 summarize the allocations that have been made for each instrument in the nominal payloads. Provision has been made for 15 percent greater mass and volume, and 20 percent greater power than that specified for the nominal payload, which provides flexibility for handling payload changes. (The thermal design was based on a negative 10 percent in mass to ensure a conservative design.) The data rate allocated also exceeds the specified levels. Table 1-3 summarizes the overall science payload capability provided for the large probe, small probe, probe bus, and orbiter and compares this with the required capability.

A few significant spacecraft decisions made as a result of experiment tradeoff studies are: 1) selection of a spin axis normal to the ecliptic plane for best observing conditions for the orbiter spacecraft (and in the interest of commonality for the probe bus cruise phase, with the probe bus reoriented for final entry), 2) selection of a Type II transit trajectory for the orbiter, allowing periapsis to be located in the preferred midlatitude region for best planetary coverage, 3) selection of a long magnetometer boom (4.4m) as the most cost-effective solution to magnetic control; and 4) selection of a separate X-band horn as the most cost-effective way to implement the dual frequency occultation experiment.

For the probes, significant decisions included: 1) providing a capability for flexible targeting of the large and small probes to meet any changes in targeting strategy as new information is learned about Venus prior to the mission, 2) provision for low entry angle targeting of the probe bus to maximize the observation time, 3) selection of a probe descent rate which enhances science by optimizing the science data return, and 4) selection of heated windows and ejectable window covers to prevent condensation and particle contamination.

The most difficult instrument integration problems for the large probe are posed by the wind altitude radar planar array antenna to be located at the probe nose; the mass spectrometer inlet system, with a large number of squibs required for opening and shutting valves, and the cloud particle analyzer mirror mount which requires an alignment to 1 milliradian throughout the descent. For the small probe, the major difficulties are the deployable sensors

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\*DLBI - Doubly-differenced very long baseline interferometry.

required for temperature and IR flux measurements and opening of a pressure port at the stagnation point, because the small probe heat shield remains with the vehicle throughout the descent.

For the probe bus, the ultraviolet spectrometer presents the major problem with regard to providing a mounting which can satisfy both a requirement for whole planet viewing at long range, and for limb scanning near the planet as well as requiring a vehicle spin rate of 60 rpm. The electron temperature probe and ion mass spectrometer also require coating of the solar cells to prevent positive charge buildup on the spacecraft from degrading particle measurements by the instruments.

For the orbiter, the most difficult integration problem is presented by the rf science, with a separate X band horn being selected as a more cost effective approach than provisions for an elevation gimbal on the high gain antenna, and the large size and location of the radar altimeter antenna presenting mounting problems. In addition, the large data storage requirements of 1 megabit at periapsis has a significant cost impact.

With regard to other candidate instruments, the magnetometers on the small probe and probe bus would have a major impact on magnetic control costs, and the large data rate requirements of the attenuated total reflection spectrometer would have an impact if it were added to the large probe. For the orbiter, the large periapsis data storage requirements of the microwave radiometer and the spin scan photometer would have a major impact.

Areas in which further studies are needed include planet scanning programs and data storage at periapsis.

TABLE 1-1. SCIENCE ALLOCATIONS FOR LARGE AND SMALL PROBES

	Instrument	Location and Pointing	Ports		Windows		Volume* cm <sup>3</sup> (in <sup>3</sup> )	Mass* kg (lb)	Average Power** W	Data Rate, bps			Squib Activated Events	Operating Region	Comments
			No.	Size cm (in)	No.	Size cm(in)				Above 20 km	20 to 44 km	Below 20 km			
Large Probe	Temperature gauge	In hemisphere, 60 deg from descent axis	-	-	-	-	115 (6.9)	0.35 (0.75)	0.6	2.5	1.25	-	-	From 15 min prior to entry to impact	Protrudes 5 cm beyond boundary layer
	Pressure gauge	Close to probe stagnation point	1	0.62 (0.25)	-	-	132 (8.1)	0.45 (1.01)	0.6	2.5	1.25	-	-	From 15 min prior to entry to impact	0.6 cm diameter connecting tube from pressure port near stagnation point to pressure sensor
	Accelerometers	At center of gravity, aligned to within 0.017 deg of descent axis	-	-	-	-	765 (46.0)	1.32 (2.9)	2.8	4.5	3.2	-	-	From 15 min prior to entry to impact	Data stored during entry blackout; makes seismic measurements after impact
	Neutral mass spectrometer	In middle bay near wall, inlet 45 deg from descent axis in lower hemisphere	1	7.62 (3)	-	-	11,305 (690)	10.4 (23.0)	14.4	60	30	12	-	From 70 km to impact	Two squibs for cover removal at 67 km, other 10 for inlet valve open/close events
	Solar radiometer	In middle bay looking outside through ±45 deg	1	1.27 (0.5)	-	-	1,840 (115)	2.6 (5.8)	4.8	12.5	1.9	-	-	From 70 km to impact	Utilizes series of angled light pipes for upward and downward viewing through ±45 deg
	Cloud particle size analyzer	In upper bay pointing 90 deg to descent axis	-	-	1	1.52 (0.6)	3,766 (230)	4.2 (9.2)	24.0	47.5	20.6	1	-	From 70 km to impact	Heated window with jettisonable covers, strut-mounted mirror in airstream
	IR flux radiometer	In lower bay, points downward	-	-	1	1.27 (0.5)	1,840 (115)	2.6 (5.8)	3.6	5.0	2.5	-	-	From 70 km to impact	Heater turned on 2 days prior to entry
	Gas chromatograph	In middle bay, inlet 45 deg from descent axis in lower hemisphere	1	0.62 (0.25)	-	-	4,715 (288)	4.1 (9.8)	7.2	12.5	11.25	2	-	From 70 km to impact	Makes 1 measurement every 20 minutes
	Hygrometer	In middle bay, with externally mounted sensor	-	-	-	-	380 (23)	0.58 (1.3)	0.3	0.7	0.7	-	-	From 70 km to impact	Only required to operate down to 44 km but remains on till impact
	Wind altitude radar	In lower bay, with planar array antenna at base of probe	2	2.54(1) x1.27(0.5)	-	-	9,424 (575)	4.6 (10.0)	48.0	2.5	1.9	-	-	From 40 km to impact	Requires a spinning probe (>5 rpm)
Small Probe	Temperature gauge	On aft step of heat shield; sensor on squib deployed swing arm	-	-	-	-	115 (7.0)	0.35 (0.75)	0.6	6.6	3.3	0.8	1	From 15 min prior to entry to impact	Sensor deployed on swing arm after entry
	Pressure gauge	In lower bay, pressure tube extends through heat shield at stagnation point	1	0.62 (0.25)	-	-	132 (8.1)	0.45 (1.01)	0.6	6.6	3.3	0.8	1	From 15 min prior to entry to impact	Pressure plug ejected from heat shield after entry to open pressure port
	Accelerometer	At center of gravity	-	-	-	-	3.8 (2.3)	1.04 (0.46)	1.2	10.1	5.1	1.9	-	From 15 min prior to entry to impact	Data stored during entry blackout
	IR flux detector	In upper bay, deployable sensor looks up and down	-	-	-	-	377 (23)	0.58 (1.4)	1.2	0.5	0.3	0.7	1	From 15 min prior to entry to impact	Sensor deployed on swing arm after entry
	Stable oscillator	In middle bay	-	-	-	-	151 (9.2)	0.4 (0.86)	0.3	-	-	-	-	From 15 min prior to entry to impact	Heater turned on 45 min prior to impact
	Nephelometer	In upper bay, looking 90 deg to descent axis	-	-	1	3.8 (1.5)	603 (36.8)	0.52 (1.15)	1.2	28.1	14.1	3.3	1	From 15 min prior to entry to impact	Heated window with jettisonable cover

\* Allocated volume and mass 15 percent greater than nominal values

\*\* Allocated power 20 percent greater than nominal values

TABLE 1-2. SCIENCE ALLOCATIONS FOR PROBE BUS AND ORBITER

Instrument	Location and Pointing	Aperture cm (in.)	Field of View deg	Volume <sup>*</sup> cm <sup>3</sup> (in. <sup>3</sup> )	Mass <sup>*</sup> kg (lb)	Average Power <sup>**</sup> W	Data Rate bps		Commands <sup>***</sup>	Operating Region	Comments
Probe Bus											
Neutral mass spectrometer	On equipment shelf, pointed directly along spin axis	8.9 (3.5)	±30 deg	9424 (575)	6.3 (13.8)	14.4	384		4	From 4 days prior to entry to burn up	Positioned far from instruments affected by large magnetic fields; i.e., ion mass spec., electron temp. probe and RPA
Ion mass spectrometer	On equipment shelf, pointed directly along spin axis	7.6 ( 3)	±30 deg	2828 (173)	1.8 (4.0)	3.0	512		4	From 4 days prior to entry to burn up	Solar array surfaces coated with insulating material to minimize positive charge buildup
Electron temperature probe	On equipment shelf, with antenna positioned 90 deg to spin axis	—	—	1725 (105)	1.2 (2.5)	3.6	128		2	From 4 days prior to entry to burn up	Requires unipotential ground plane; whip-type antenna deployed at nose cone ejection
UV spectrometer	On equipment shelf, angled off the spin axis 20 deg	10.2 ( 4)	1 to 2 deg	2639 (161)	3.0 (7.0)	1.8	512		6	From 4 days prior to entry to burn up	Requires 60 rpm spin rate, turned on 4 days prior to entry for view of entire planet
Retarding potential analyzer	On equipment shelf, pointed directly along spin axis	5.1 ( 2)	±30 deg	2262 (138)	1.4 (3.0)	3.0	320		4	From 4 days prior to entry to burn up	Part of thermal blanket around RPA aperture plated to act as a ground plane
Orbiter							Above 4000 km	Below 4000 km			
Magnetometer	On a 4.4 m boom at 90 deg to spin axis	—	—	4528 (276)	4.0 (8.8)	4.8	3	33.7	4	Entire orbit	Also operates during cruise phase - 3 bps
Solar wind analyzer	Mounted on outer edge of equipment shelf, and views 90 deg spin axis through solar substrate	2.5 x 0.64 (1.0 x 0.25) 1.3 x 0.64 (0.5 x 0.25)	140 x 20 deg	6333 (386)	5.8 (12.6)	6.0	3	—	4	Entire orbit except ±30 min at periapsis	Also operates during cruise phase - 3 bps
Electron temperature probe	On equipment shelf with antenna positioned 90 deg to spin axis	—	—	2262 (138)	1.6 (3.5)	3.0	—	26.2	5	±30 min about periapsis	Area of substrate around base of probe finished to provide ground-plane, solar array surfaces coated to minimize charge buildup
Neutral mass spectrometer	On equipment shelf, offset 56 deg from spin axis	5.1 ( 2)	±30 deg	9424 (575)	6.2 (13.8)	14.4	4000 km to 500 km	Below 500 km	7	±30 min about periapsis	Positioned far from magnetometer boom and charged particle. Instruments to minimize interference require coating of solar array to minimize charge buildup.
Ion mass spectrometer	On equipment shelf, offset 56 deg from spin axis	7.6 ( 3)	±30 deg	3770 (230)	1.7 (3.7)	2.4	4000 km to 500 km	Below 500 km	4	±30 min about periapsis	
UV spectrometer	On outer edge of equipment shelf looking through solar substrate at 90 deg to spin axis	10.2 ( 4)	2 deg	7519 (460)	6.3 (13.8)	7.2	Above 4000 km	Below 4000 km	4	Entire orbit	Might also operate during cruise phase
IR radiometer	On equipment shelf, offset 34 deg from spin axis	7.6 ( 3)	1 to 2 deg	7519 (460)	6.3 (13.8)	7.2	Above 3000 km	Below 3000 km	4	±30 min about periapsis	Requires low spin rate (~5 rpm)
X band occultation	On equipment shelf; uses communication antenna	—	3 deg, X band 11 deg, S band	4528 (276)	3.1 (6.9)	14.4	NA	NA	4	During occultations	Operates only during occultation season
Radar altimeter	Antenna positioned above equipment shelf, offset 34 deg from spin axis	55.9 x 40.6 (22.0 x 16.0)	30 deg, AZ 14 deg, EL Pointable over ±45 deg elevation	11309 (690)	10.3 (23.0)	48.0	Above 1000 km	Below 1000 km	5 +1 magnitude command	±10 min about periapsis	Requires low spin rate (~5 rpm)

\* Allocated volume and mass 15 percent greater than nominal values

\*\* Allocated power 20 percent greater than nominal values

\*\*\* Does not include ON/OFF commands

TABLE 1-3. OVERALL SCIENCE PAYLOAD CAPABILITY

	Mass, kg (lb)		Volume, cm <sup>3</sup> (in. <sup>3</sup> )		Power, W		Data Rate, bps	
	Required	Provided	Required	Provided	Required	Provided	Required	Provided
Large probe	27.2 (60.5)	31.3 (69.5)	29,800 (1823)	34,270 (2096)	88.6	106.3	136	152
Small probe	2.2 (4.9)	2.5 (5.6)	1231 (75.0)	1416 (86.2)	4.25	5.1	51	53
Probe bus	12.0 (26.4)	13.8 (30.4)	16,420 (1001)	18,883 (1152)	21.5	25.8	1640	1856
Orbiter	39.5 (86.9)	45.4 (99.9)	50,760 (3036)	58,374 (3491)	89.5	107.4	443	517



## 2. INTRODUCTION

"There are a whole series of problems to be addressed to the planet Venus, and provided the Gods are willing, the carefully orchestrated series of probes known as Pioneer Venus will answer these problems in the next decade."

T. M. Donahue, December 1972 (Reference 2-1)  
AAAS Annual Meeting, Washington, D. C.

The strategy for the exploration of Venus through a variety of low cost missions utilizing a spinning, Pioneer class, spacecraft has been evolved in a number of advisory group studies since the flyby of Venus by Mariner 5 in 1967 (References 2-2 through 2-6). The scientific questions to be answered require a highly coordinated set of experiments.

Despite the fact that Venus is the third brightest object in the heavens, and the twin of earth, we know much less about it than about Mars, even though it has been visited by five Soviet probes. Venus hides itself under a veil of clouds, but various investigations have nevertheless told a great deal about Venus and the class of problems that exist.

J. E. Naugle recently pointed out (Reference 2-7) that the first quantum jump in planetary science came with Galileo's invention of the telescope, the second quantum jump came from radio and radar astronomy after World War II, and the third quantum jump occurred in December 1962 when Mariner 2 flew by Venus, which completely changed the character of planetary observations.

A chronology of discoveries about Venus over the last decade is as follows. On 14 December 1962 Mariner 2 flew by Venus at 35,000 km altitude, and revealed that Venus had no magnetosphere, and had a high surface temperature. Five years later, in October 1967, Venera 4 entered the Venus atmosphere, and Mariner 5 flew by at 3900 km. They discovered that Venus had a CO<sub>2</sub> atmosphere with only traces of water vapor, and confirmed high surface temperatures and high atmospheric pressures. Venera 5 and Venera 6 in May 1969 further confirmed earlier results. Venera 7 in December 1970 extended the temperature profile data to the surface and found a temperature of 750°K and a pressure of 90 atmospheres, with a lapse rate of 8.6°K/km all

the way to the surface. Venera 8 on 22 July 1972 found that the surface composition resembles granite rock on Earth, and that a certain amount of visible light penetrates to the surface. It also reported small amounts of ammonia in the atmosphere.

Radar astronomical studies have told us that the radius of Venus is  $6050 \text{ km} \pm 5 \text{ km}$ , and that the surface has a relief structure. The orbital period is 225 days, but the rotation period is extremely slow (243 days) and retrograde. Sunrise occurs every 118 days in the west.

Surface temperature can be studied by earth-based radiometry, and the most significant fact besides the high surface temperature is the low temperature gradient that exists over the planet;  $12^\circ \text{K}$  from equator to pole, and  $20^\circ \text{K}$  from day to night (Reference 2-1).

At the cloud tops there is a 4-day rotation, also retrograde, corresponding to wind velocities of about  $100 \text{ m/sec}$ , as determined by earth-based measurements. Ultraviolet markings appear to move about the planet with an apparent period of 3.6 to 4.5 days, and Doppler shifts in the solar spectrum reflected by Venus indicate a rotation period of  $4.3 \pm 0.4$  days, (Reference 2-8).

An analysis of the Venera 4, 5, 6, and 7 descent data (Reference 2-9) suggests that the high altitude band of retrograde horizontal winds extends downward to the one atmosphere level ( $\sim 50 \text{ km}$ ). In the region between one and two atmospheres the wind decreases to  $10$  to  $20 \text{ m/sec}$  and then remains constant down to the 17 atmosphere level. At the 20 atmosphere level ( $\sim 25 \text{ km}$ ), the analysis suggests a second retrograde horizontal wind layer with a speed of roughly  $35 \text{ m/sec}$ , decreasing to the order of  $0.1 \text{ m/sec}$  at the surface. The correlation between the Venera 7 vertical wind and temperature lapse rate profiles and the Mariner 5 S-band attenuation coefficient profiles suggests the existence of several additional clouds lying beneath the visible cloud layer.

There is a thin cloud layer at  $81 \text{ km}$  ( $3 \text{ mbar}$ ) and  $175^\circ \text{K}$ . Earth-based polarization measurements indicate spherical drops with an index of refraction  $n = 1.45$ . The most popular model of these clouds until very recently, has been  $\text{HCl} \cdot \text{H}_2\text{O}$ , but at the Planetary Sciences meeting in Tucson this March, several papers were presented which indicate that the best agreement with the measured data is obtained by a water solution of sulfuric acid, containing 75 or 85 percent of  $\text{H}_2\text{SO}_4$  by weight (References 2-10 and 2-11).

There is a thick cloud layer of unknown composition at  $61 \text{ km}$  ( $240 \text{ mbar}$ ) and  $260^\circ \text{K}$ . Below these two cloud layers are probably other cloud layers. Water in the amounts detected by the Venera spacecraft can be used to explain the clouds at  $60 \text{ km}$ , and Mariner 5 temperature measurements support this explanation; however, analysis of the geochemistry of Venus suggests mercury compounds (specifically, a thin haze of  $\text{Hg}_2\text{Cl}_2$  overlaying a deep cloud of mercury droplets) as more likely components of the lower cloud layer (Reference 2-12).

Potential cloud layers have been identified from Mariner 5 occultation data at temperatures of 402°K (corresponding to an altitude of 44 km) and of 371°K (corresponding to an altitude of 47 km). A chemical model of the atmosphere with mercury bromide ( $\text{Hg}_2\text{Br}_2$ ) at 44 km and mercury iodide ( $\text{Hg}_2\text{I}_2$ ) at 47 km has been proposed (Reference 2-12). Cloud layers in the 37 to 50 km region have been postulated on the basis of the S-band loss coefficient observed by Mariner 5 (Reference 2-14).

First order questions about Venus at the present time include: the nature of the clouds, the global circulation of the atmosphere, why Venus has such a high surface temperature, why the  $\text{CO}_2$  is stable, whether Venus has a magnetic moment, and what its seismic characteristics are.

These questions are not just of interest in connection with Venus. Planetary studies are important with respect to studies of our own planet. Professor R.M. Goody of Harvard stated in a presentation to the House Subcommittee on Space Science and Application on 15 March 1973 (Reference 2-15), that it is no longer possible or desirable to consider Earth entirely aside from the other planets. In the poorly understood areas of meteorology and climatology, the inner planets, Venus, Earth, and Mars, provide us with a laboratory of different systems. Venus has about 100 times the surface pressure of Earth, which in turn has a pressure more than 100 times that of Mars. Earth has a surface mainly covered by oceans, while the surface of Mars and Venus are solid. Mars and Earth rotate at almost the same rate and have similar seasonal changes; Venus rotates 240 times slower and has no seasons. The Earth is approximately half covered with clouds of water droplets, while Venus is totally covered by clouds of an unknown nature and on Mars the most important clouds are formed of surface dust.

Before the same committee, Professor M.B. McElroy pointed out that Venus absorbs approximately the same quantity of incident solar energy as does Earth (although it is closer to the sun it has a higher albedo than Earth). Yet the temperature at the surface of Venus is almost three times as hot as the average temperature at the surface of Earth. Is Venus hot because of some potent greenhouse effect? Were there primitive oceans on the surface of Venus which contributed to this greenhouse, but which have since boiled off into interplanetary space? Could a similar fate be in store for Earth, promoted perhaps by increased pollution of the air we breathe (Reference 2-16)?

There are two major candidate theories as to why Venus is hot, both of which have problems. In the greenhouse model, visible sunlight penetrates to the surface where heat is absorbed and can't radiate out. Earth has a 20 or 30°K greenhouse effect due to water vapor in the atmosphere. If the level of atmospheric pollution is increased, then the greenhouse effect increases; this increases the surface temperature and increases the evaporation of water vapor from the ocean. Thus a runaway greenhouse effect might result with the temperature rising to the temperature of Venus (Reference 2-17).

The difficulty with the greenhouse model is that it is very hard to find materials that transmit visible and block out infrared radiation. It has not been possible to explain a temperature of higher than 400 – 450° K by this theory in detail. One serious problem is to explain why there is so little difference in the day side and the night side temperature.

A second approach is the Goody and Robinson model which assumes that absorption occurs at the top of the atmosphere and a circulation pattern is set up called Hadley circulation. The atmosphere gets hot at the bottom just due to adiabatic motion--heating due to compression. But the observed fact is that the surface of Venus is rotating very slowly, while the top of the atmosphere is moving very rapidly. There have been attempts to explain this as a nonlinear phenomena associated with the sun moving with respect to the atmosphere (the moving flame theory), an effect which has been observed in laboratory experiments.

Another very interesting question about Venus is why the CO<sub>2</sub> atmosphere is stable. If CO<sub>2</sub> is irradiated with ultraviolet radiation, it decomposes into CO and O, and recombines with great difficulty, since the atomic oxygen tends to form O<sub>2</sub>. But Venus has extremely small amounts of CO (one part in 10<sup>4</sup>) and O<sub>2</sub> (less than one part in 10<sup>6</sup>) as determined by spectroscopy from Earth.

One theory, proposed by McElroy, (Reference 2-17) is that the stability depends on the existence of HCl, which is present to one part in 10<sup>8</sup>, as follows. UV penetrates to a 1 mbar altitude and dissociates CO<sub>2</sub> into CO and O<sub>2</sub>, which diffuse downward and then are catalytically combined. HCl dissociates at a longer wavelength, which penetrates more deeply, and catalyzes the combination of CO and O<sub>2</sub> into CO<sub>2</sub>. Since hydrogen is crucially important in stabilizing the CO<sub>2</sub>, the question is where the hydrogen comes from. The answer would appear to be the solar wind. The solar wind hydrogen is believed to get into the atmosphere through a complicated flow process, which orbiter experiments should clarify.

This brief introduction has attempted to summarize what is currently known about Venus, and identifies some of the many interesting science questions that the Pioneer Venus mission is being designed to answer.

### 3. MULTIPROBE MISSION

The Pioneer Venus mission set consists of a multiprobe mission and an orbiter mission. Originally, the probe spacecraft was to be launched in 1977 and the orbiter in 1978; however, at the present time, both are scheduled for launch in 1978.

The probe spacecraft consists of a bus, large probe, and three small probes. It is spin stabilized and uses solar power. Initial studies were carried out for both a Thor/Delta and an Atlas/Centaur launch vehicle. The decision has now been made by NASA to employ the Atlas/Centaur.

The launch window for the multiprobe mission is 8-21 August 1978, with an arrival date of 9 December. The transit geometry is shown in Figure 3-1. The probes will be separated from the bus 20 days prior to encounter.

#### 3.1 SCIENCE OBJECTIVES

The science objectives of the multiprobe mission are to determine (Reference 3-1):

- 1) The nature and composition of the clouds
- 2) The composition and structure of the atmosphere
- 3) The general circulation pattern of the atmosphere

The nature of the many questions to be resolved has been discussed in Section 2. The significant regions of the Venus atmosphere are shown in Figure 3-2 (Reference 2-8) in terms of the temperature profile, as a framework for discussing the measurements to be made by the large probe, small probe, and probe bus science payloads.

The ionosphere extends from an altitude of several thousand kilometers on the night side and from about 500 on the day side down to the turbopause, with the peak electron density occurring at about 140 km for both day side and night side (as determined from Mariner 5 occultation data).

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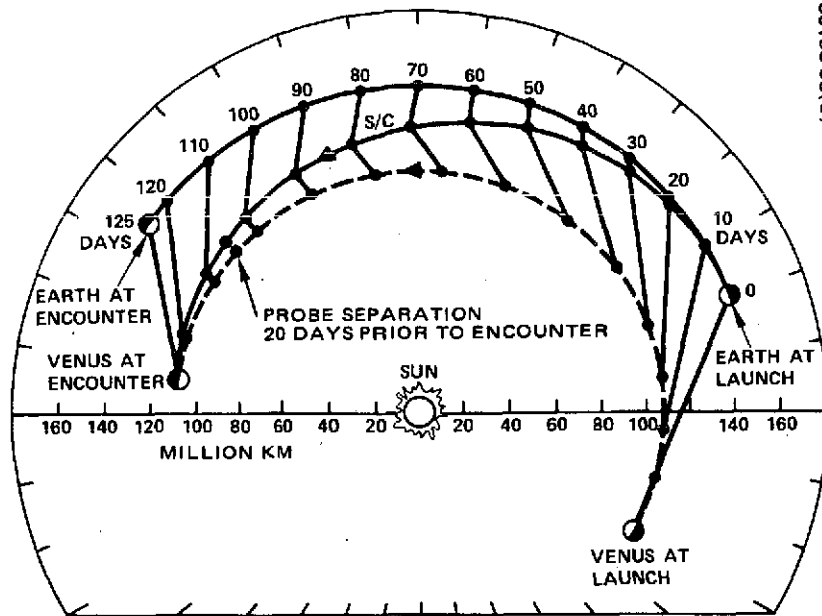
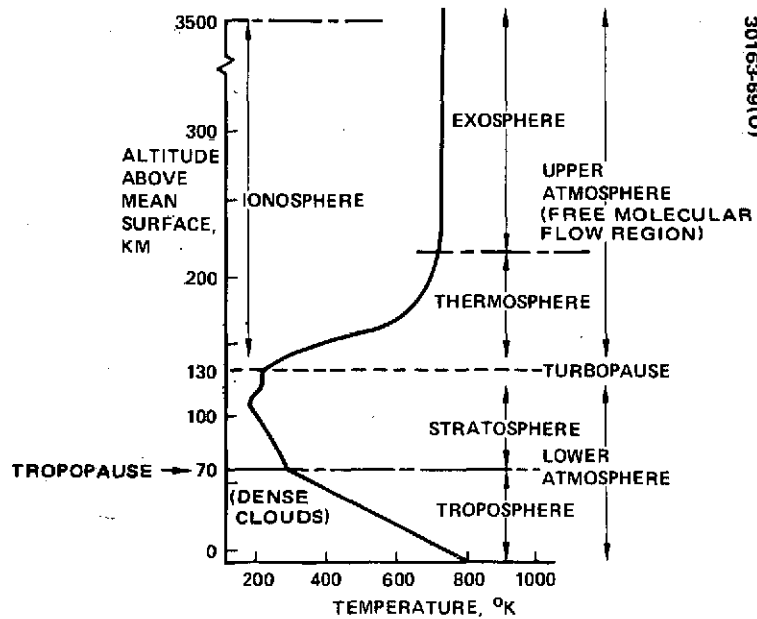


FIGURE 3-1. MULTIPROBE MISSION TRANSIT GEOMETRY



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FIGURE 3-2. THERMAL STRUCTURE OF VENUS ATMOSPHERE

The turbopause marks the transition between free molecular and viscous flow and occurs at an altitude of about 130 km. The region above the turbopause is called the upper atmosphere, and the region below the lower atmosphere.

The dense cloud cover begins at the tropopause, which separates the stratosphere, where temperature is roughly constant, and the troposphere, where the change of temperature with altitude is constant. The tropopause occurs at about 70 km altitude.

Based on this knowledge of the atmospheric regions, the specific objectives of the probe measurements are described in the subsections that follow.

### Large Probe

The large probe will conduct a detailed sounding of the troposphere, obtaining in-situ measurements of the structure, composition, and clouds from 70 km to the surface. Primary emphasis is on the planet's energy balance and clouds--their nature, distribution, composition, and interaction with light and thermal radiation. Wind speed will also be measured during the descent. Figure 3-3 shows a typical large probe entry and descent trajectory, with the parachute deployed at about 70 km and jettisoned at 40 km. Most science instruments begin operation at parachute deployment.

Limited information on the stratosphere may also be obtained, from observations of the interaction of the probe deceleration with the atmosphere. However, the large probe passes very rapidly through the stratosphere, taking about half a minute, while the descent through the troposphere takes an hour or more; thus, little time is available for measurements in this region.

### Small Probes

The small probes, entering at points widely separated from the large probe, will provide information on the general circulation pattern of the lower atmosphere. It is anticipated that the important motions have a global scale; hence, a few observations can illuminate some of the important physics and dynamics of the atmosphere (Reference 2-5).

Figure 3-4 shows a typical small probe entry and descent trajectory. The most important measurements to be made are temperature as a function of pressure, and wind velocity. It is also desirable to measure the presence of clouds and the energy flux as a function of pressure (or altitude).

### Probe Bus

The probe bus will provide data on the upper atmosphere and ionosphere down to the altitude at which the probe bus becomes inoperative due to overheating, which is expected to be just beyond the turbopause. Of particular interest is the altitude region below the minimum orbiter altitude of 150 to

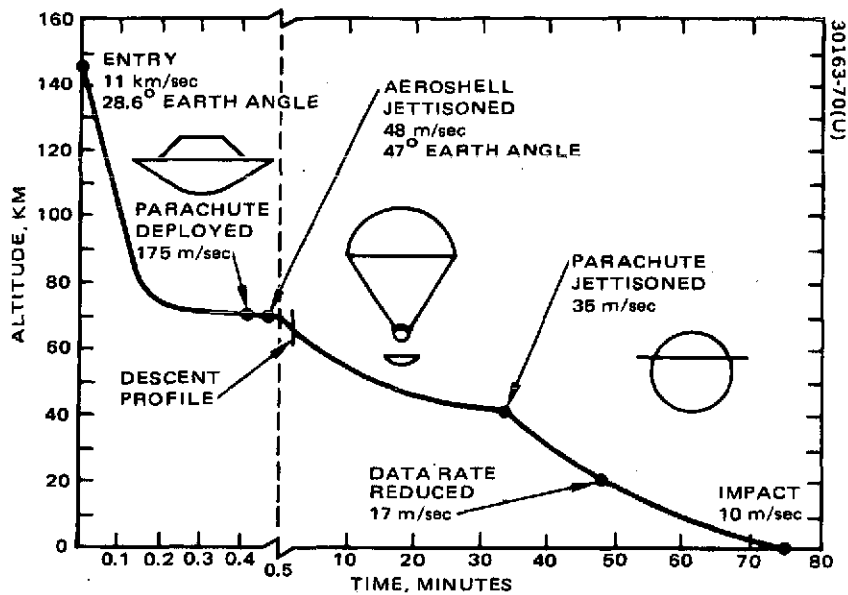


FIGURE 3-3. LARGE PROBE ENTRY AND DESCENT

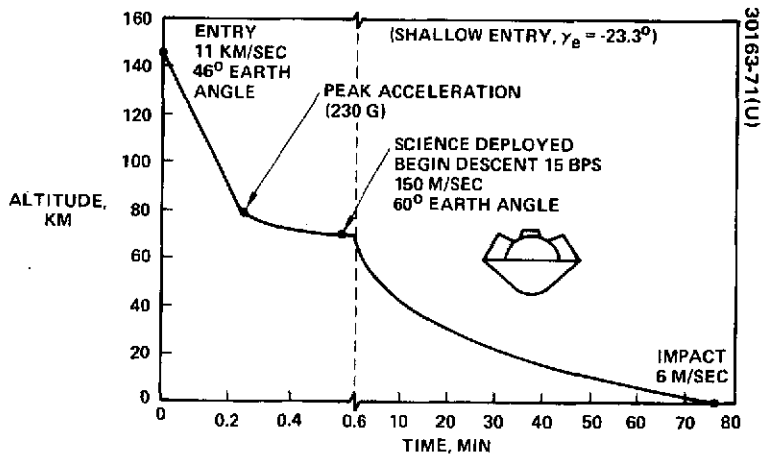


FIGURE 3-4. SMALL PROBE ENTRY AND DESCENT



200 km. Upper atmosphere composition measurements are particularly important in understanding the chemical processes which account for the stability of the CO<sub>2</sub>.

Figure 3-5 shows the probe bus time history from an altitude of 2000 to 130 km, a time interval of about 8 minutes. This trajectory assumes that a shallow entry ( $\gamma = -12$  deg) is employed for maximum observation time at the lower altitudes before burnup.\* Less than a minute is available below 200 km.

Instruments may also be included in the probe bus payload which can return useful information during the interplanetary cruise.

The probe bus entry is delayed by 1.5 h from the entry of the probes, so that it can provide an accurate positional reference for long baseline interferometric measurements of probe position and velocity during entry.

### Targeting Requirements

The large probe is constrained to enter on the day side, not closer than 20 deg to the terminator, so that the sun is not near the horizon (Reference 2-5). It must also maintain an acceptable communication angle after release.

The small probes are widely separated to give the greatest coverage in latitude and longitude within acceptable earth communication angle limits. The minimum acceptable spread in latitude is  $\pm 30$  deg, and in longitude is 90 deg (Reference 2-5). Day or night entry is acceptable for the small probes. It is desirable to have at least one probe at the highest possible latitude.

Another consideration for targeting of the small probes is to minimize critical design requirements imposed by steep entry angles, such as high g loads, and to reduce the range of entry angle designs for all probes.

The probe bus targeting is constrained by the requirements for a very low entry angle to obtain maximum observation time. It enters on the day side at high latitude

Typical targeting of the probes and probe bus for the 1977 mission is shown in Figure 3-6. Details of the targeting tradeoffs are contained in Study Task Report MS 5, Nominal Probe Target Locations, 5 February 1973.

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\*The Pioneer Venus Science Steering Group in its June 1972 report recommended a steep entry for maximum penetration of the atmosphere; however, this position was reversed at the 1 December 1972 review meeting at NASA/ARC, at D. Hunten's recommendation, (Reference 3-2).

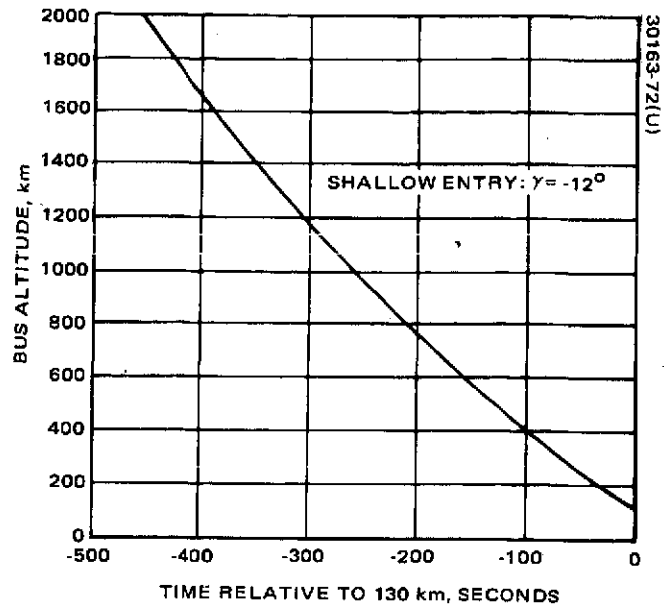


FIGURE 3-5. PROBE BUS ALTITUDE-TIME HISTORY

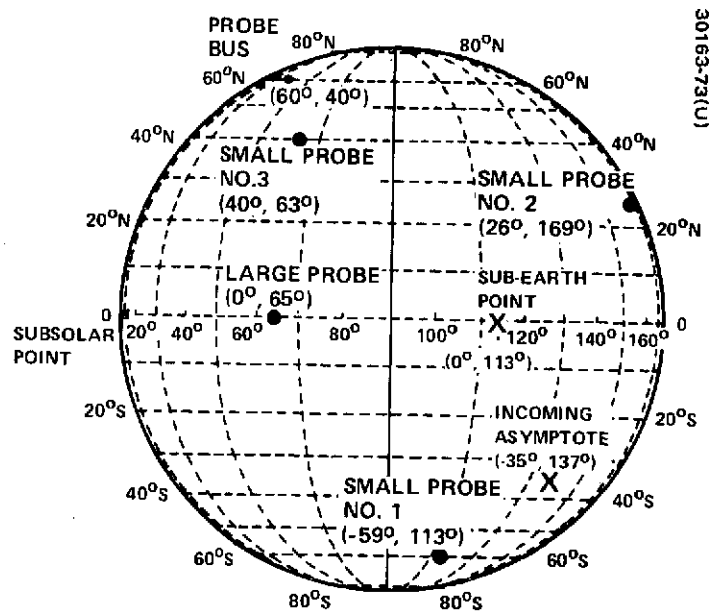


FIGURE 3-6. MULTIPROBE TARGETING FOR 1977 MISSION

### 3.2 SCIENCE PAYLOAD

The science payload for the multiprobe mission has been evolving continuously during the course of the study and before presenting specific payloads it will be useful to provide an overview of the payload definition sequence.

An initial science payload for the multiprobe mission was provided by NASA/ARC on 20 September and discussed at the first Pioneer Venus science briefing on 4 October 1972 (Reference 3-3). This payload consisted of 23 nominal and 6 other candidate instruments for the large probe, small probe, and probe bus,\* assuming a Thor/Delta launch vehicle.

On 20 October a revised payload was provided for use with the Atlas/Centaur launch vehicle (Reference 3-4). This payload differed only in having increased mass, power, and volume allotments for some instruments.

Early in December, updated information on a large number of the experiments was presented and this was documented on 19 December by a set of preliminary experiment interface descriptions for 17 experiments (8 large probe, 6 small probe, and 3 probe bus experiments) for Thor/Delta (Reference 3-5). This data, plus unchanged earlier payload data, was utilized as the science baseline for the Pioneer Venus midterm design review of 26 February.

On 13 February, NASA/ARC held a science briefing at which information was provided on specific proposals which NASA had received for both nominal and other candidate instruments (Reference 3-6). Alternate instrument designs under consideration for several of the nominal payload experiments were presented, and a number of new candidate instruments were described.

At the end of March, the decision was made by NASA to proceed with the Atlas/Centaur version of Pioneer Venus, and on 18 April a new payload (Reference 3-7) was received, reflecting this decision. This payload has served as the baseline for the remainder of the study. There are 22 nominal instruments and 8 other candidate instruments.

Throughout the study, to become more familiar with the experiments under consideration and with possible added experiments, Hughes made a number of visits to science investigators who had proposed or were considering proposing experiments for Pioneer Venus. Several pertinent scientific symposia were also attended. Table 3-1 summarizes the science contacts and briefings and references the trip reports which document the data obtained. These reports, together with those documenting orbiter science contacts listed in subsection 4.2, have been collected together in an appendix to this volume.

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\*Orbiter science payloads were also provided. These are discussed in subsection 4.2.

TABLE 3-1. EXPERIMENT INTEGRATION SCIENCE CONTACTS AND BRIEFINGS  
(MULTIPROBE MISSION)

Date	Name	Affiliation	Area of Discussion	Reference
26 Sept 72	A. I. Stewart	U. of Colorado	UV spectrometer	HS 507-0224
27 Sept 72	R. Young	York University	UV fluorescence	HS 507-0226
28 Sept 72	N. W. Spencer	NASA/GSFC	Mass spectrometers	HS 507-0230
29 Sept 72	J. S. Lewis	MIT	Venus atmosphere	HS 507-0230
29 Sept 72	I. I. Shapiro	MIT	DLBI	HS 507-0220
4 Oct 72	J. Sperans	NASA/ARC	First Pioneer Venus science briefing	HS 507-0225
1 Nov 72	W. B. Hanson	U. of Texas	Upper atmosphere experiments	HS 507-0260
3 Nov 72	L. Goldfischer	Singer-Kearfott	Wind-drift radar study	HS 507-0273
8 Dec 72	J. Sperans	NASA/ARC	Probe science payload update	HS 507-0338
29 Dec 72	AAAS Meeting Washington, D. C.	AAAS	NASA planetary research	HS 507-0377
11 Jan 73	J. Sperans	NASA/ARC	Magnetometer	HS 507-0382
18 Jan 73	H. Alfven	Royal Inst. of Tech. Stockholm	Evolution of the solar system (Lecture at Cal State, Northridge)	HS 507-0404
31 Jan 73	M. E. McElroy	Harvard U.	Science objectives for exploration of Venus	HS 507-0413
13 Feb 73	J. Sperans	NASA/ARC	Science payload briefing	HS 507-0434
9 Mar 73	S. C. Sommer	NASA/ARC	Accelerometer, temperature, and pressure	HS 507-0455
12 Mar 73	M. Kolpin L. Harnett	TRW TRW	Mass spectrometer Hygrometer	HS 507-0461
19 Mar 73	R. Knollenberg	Particle Measuring Co.	Cloud particle size analyzer	HS 507-0480
20 - 23 Mar 73	Planetary Sciences Meeting, Tucson	DPS/AAAS	Recent research in planetary science	HS 507-0532
5 Apr 73	V. Suomi	U. of Wisconsin	Small probe experiments	HS 507-0489
6 Apr 73	W. Fastie R. Hanel	Johns Hopkins U. NASA/GSFC	UV spectrometer Nephelometer	HS 507-0489
9 Apr 73	A. Young	JPL	Sulfuric acid clouds	HS 507-0497
13 Apr 73	A. L. Fymat	JPL	Solar radiometer	HS 507-0534

To provide a standard data source on the experiments which all systems engineers could use, an Experiment Engineering Data Book was compiled, in which data was given in a standard format for each of the nominal instruments, utilizing data from all available sources. This book is being published separately as an output of Experiment Study Task EX 2. Periodically updated, this has been the primary reference document in the experiment area.

In the following sections, the science payloads which have served as baselines in this study will be summarized, beginning with the payloads considered for the Thor/Delta and Atlas/Centaur launch vehicles at the mid-term review. The new Atlas/Centaur payload is then presented and compared with the earlier payload.

### Large Probe

The Thor/Delta nominal science payload for the large probe is shown in Table 3-2, with the initial Atlas/Centaur figures shown in brackets where different. The instruments carried were: temperature sensors, pressure sensors, accelerometers, neutral mass spectrometer, cloud particle size spectrometer, solar flux radiometer, planetary flux radiometer, aureole extinction detector, nephelometer, shock layer radiometer, and hygrometer. Total payload mass was 22.4 kg (49.6 lb). The Atlas/Centaur payload was slightly larger; 26.0 kg (57.5 lb).

Data rate and geometry requirements are shown in Table 3-3. The basic data rate requirement, given in bits/sample and samples/min., has been converted to an average bits/sec rate. The measurement objective for each experiment is shown in Table 3-4, and also the number of samples obtained in each atmospheric scale height, for the specified sampling rate. The scale heights are numbered from the surface, as shown in Figure 3-7, which presents the large probe descent profile. The dotted curve shows an alternate descent curve that jettisons the parachute at 40 km rather than 55 km, providing greater observation time over some potential cloud layers. Because of an added mass penalty, this trajectory was not used for the Thor/Delta mid-term baseline but it was used for the Atlas/Centaur baseline.

To compensate for the shorter descent times associated with earlier parachute jettison, a greater sampling rate capability than specified was provided in the Hughes design, as shown in Table 3-5. In the lowest scale height, where there is increased atmospheric attenuation, the data rate is reduced to two-thirds of its value at the higher altitudes. Because the probe is traveling so slowly in this region, the samples per scale height and per kilometer are still high. Samples per kilometer are shown in Figure 3-8. The minimum sampling occurs in the fourth scale height, where the capability shown in Table 3-5 is generally quite adequate. The neutral mass spectrometer is a special case. It requires fewer samples than the other instruments.

The current Atlas/Centaur nominal payload is shown in Table 3-6. The payload mass has been increased still further to 27.2 kg (60.5 lb).

TABLE 3-2. THOR/DELTA LARGE PROBE SCIENCE PAYLOAD  
(December)

Instrument	Mass		Average Power, W	Volume	
	kg	lb		cm <sup>3</sup>	in <sup>3</sup>
Temperature sensing system	0.6 (0.7)	1.3 (1.5)	1.0	200	12
Pressure sensing system	0.8 (0.9)	1.8 (2.0)	1.0	230 (260)	14 (16)
Accelerometer	1.1	2.5	2.3* (3.0)*	655	40
Neutral mass spectrometer	7.7 (9.0)	17.0 (20.0)	12.0 (14.0)	10650	650
Cloud particle size spectrometer	3.6 (4.5)	8.0 (10.0)	20.0	3280 (3930)	200 (240)
Solar flux radiometer	1.8 (2.3)	4.0 (5.0)	4.0 (4.5)	1965 (2950)	120 (180)
Planetary flux radiometer	2.3	5.0	4.0	1965 (2950)	120 (180)
Aureole extinction detector	1.8 (2.0)	4.0 (4.5)	2.0 (2.5)	1965 (2460)	120 (180)
Transponder	**	**	**	**	**
Nephelometer	1.0 (1.6)	2.5 (3.5)	2.0 (4.0)	1310 (1965)	90 (120)
Shock layer radiometer	1.1	2.5	1.0	440 (980)	27 (60)
Hygrometer	0.5	1.0	0.25	200 (330)	12 (20)
Total science payload	22.4 (26.0)	49.6 (57.5)	49.55 (55.25)	22860 (27330)	1395 (1668)

COMMENT: ( ) = Initial Atlas/Centaur values if different from Thor/Delta

\*Power for 0.0 g accelerations; 8 mW additional power required per g.

\*\*The transponder is included in the telecommunications system.

TABLE 3-3. THOR/DELTA LARGE PROBE SCIENCE PAYLOAD  
GEOMETRY AND DATA RATE REQUIREMENTS

Instrument	Geometry Requirements	Data Requirements		
		Bits/ Sample <sup>(1)</sup>	Samples/ Min.	Bits/Sec <sup>(2)</sup>
Temperature sensing system	Mount in area of large smooth mass flow	20	6.0	2.1
Pressure sensing system	Place inlet port at stagnation point	20	3.0	1.1
Accelerometer	Mount at c. g. with descent axis aligned to 0.017 deg of spin axis			
Entry <sup>(3)</sup>		10	480.0	80.0
Blackout <sup>(4)</sup>		40	150.0	100.0
Post-blackout <sup>(5)</sup>		40	60.0	40.0
Descent { Axial		20	3.0	1.0
{ Lateral		20	1.5	0.5
Seismic		10	360.0	60.0
Neutral mass spectrometer	A 7.6 cm (3 in.) diameter tube extended beyond boundary layer at 60 +15 deg to spin axis facing toward Venus	15,000	1/6	42.0
Cloud particle size spectrometer	Mount in large smooth mass flow area perpendicular to mass flow. Mirror alignment must be within 1.0 mr of source beam	240	16.0	67.0
Solar flux radiometer	Field of view (El and Az) 90° by 30° and aligned normal to spin axis so instrument may look up and down	100	2.4	4.0
Planetary flux radiometer	The FOV is 5 deg looking along local vertical aligned to spin axis (±1 deg)	100	2.4	4.0
Aureole extinction detector	(El and Az) 15 by 0.5 deg, aligned so sun is intercepted by the FOV each revolution	64	24.0	26.0
Nephelometer	Source FOV is 0.5 deg looking up 20 to 25 deg to spin axis. Detector FOV is 5 to 10 deg looking down 20 to 25 deg to spin axis. Detector's FOV must intercept source's FOV at angle of 47 ±7 deg	20	24.0	11.0
Shock layer radiometer <sup>(3)</sup> (blackout only)	FOV is approximately 20 deg; this instrument to be mounted at aeroshell stagnation point, looking at the shock layer	84	150.0	210.0
Hygrometer	Mount in a region of large, smooth mass flow	21	6.0	2.0

(1) Science data only

(2) Science and science engineering data

(3)  $4 \times 10^{-4}$  g to 0.5 g (data stored)

(4) 0.5 g to 0.5 g during peak deceleration ( 10 sec - data stored)

(5) End of blackout until parachute deployment (data stored)

TABLE 3-4. LARGE PROBE DESCENT MEASUREMENTS  
(REQUIRED SAMPLING RATE)

Instrument	Measurement Objective	Samples/ Min	Samples/Scale Height <sup>(1)</sup>							
			1	2	3	4	5	6	7	8
Temperature sensor	Temperature profile to impact	6.0	150	66	36	15	30	18	-	-
Pressure sensor	Pressure profile to impact	3.0	75	33	18	7.5	15	9	-	-
Accelerometers	Deceleration history	3.0	75	33	18	7.5	15	9	30 <sup>(2)</sup>	5 <sup>(2)</sup>
	Atmospheric turbulence	8.6	214	94	51	21	43	4.3	0.7	
Neutral mass spectrometer	Atmospheric and cloud constituents	1/6	4.2	1.8	1	0.4	0.8	0.5	-	-
Cloud particle size analyzer	Cloud particle size	16.0	400	176	96	40	80	48	-	-
Solar flux radiometer	Deposition of solar energy in atmosphere	2.4	60	26	14	6	12	7	-	-
Planetary flux radiometer	IR radiation from planet	2.4	60	26	14	6	12	7	-	-
Aureole detector	Extinction of sunlight and particle size	24.0	-	-	144	60	120	72	-	-
Nephelometer	Presence of clouds	24.0	600	264	144	60	120	72	-	-
Shock layer radiometer	Radiation from heated atmosphere during entry	-	-	-	-	-	-	-	-	-
Hygrometer	Water vapor content	6.0	-	-	-	15	30	18	-	-
Transponder	Wind velocity	Continuous								

(1) For baseline trajectory

(2) Post blackout mode 1 sample/sec

(3) Post blackout mode 1/7 sample/sec



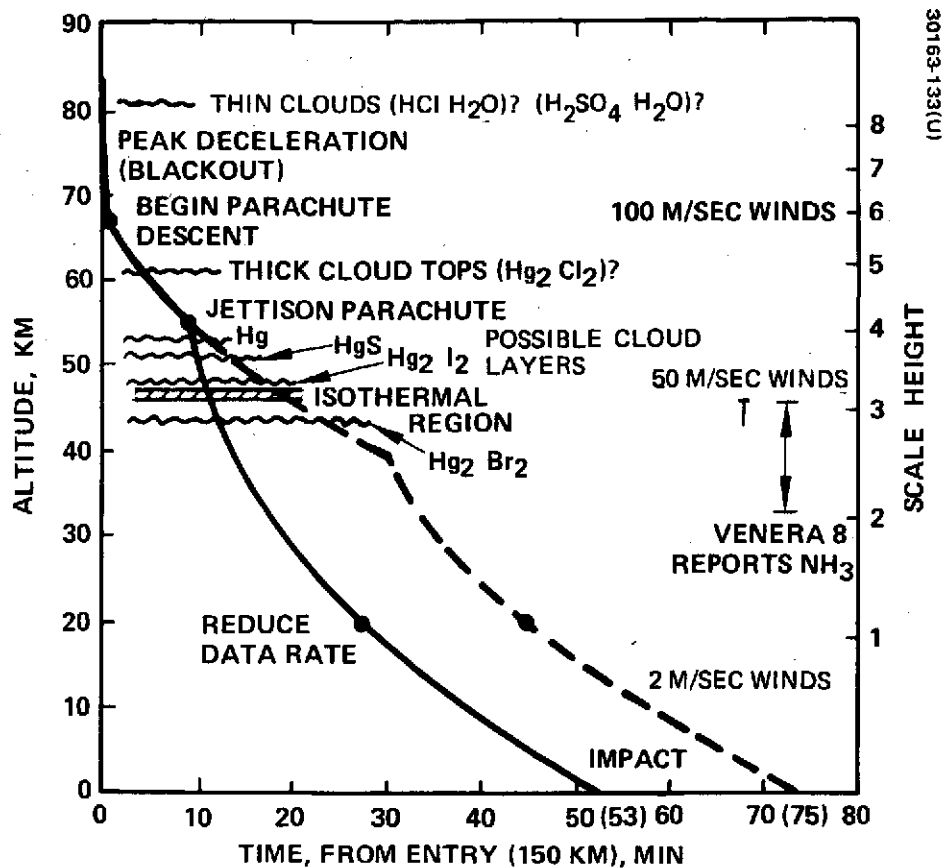


FIGURE 3-7. LARGE PROBE DESCENT PROFILE

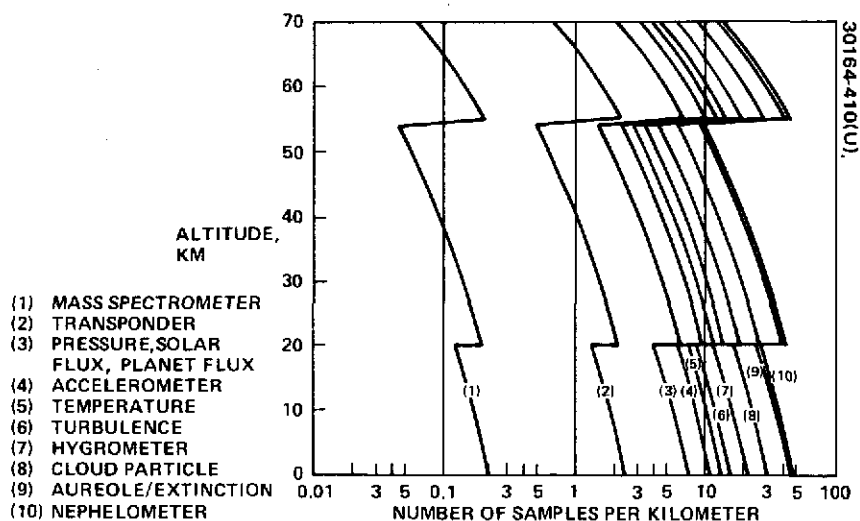


FIGURE 3-8. LARGE PROBE SCIENCE RETURN

TABLE 3-5. LARGE PROBE SCIENCE MEASUREMENTS  
(CAPABILITY PROVIDED)

Instrument	Samples/Min	Samples/Scale Height	
		1	4
Temperature	12	200	30
Pressure	6.6	110	16.5
Accelerometer*	3	75	7.5
Neutral mass spectrometer	0.19	3	0.4
Cloud particle size analyzer	26.4	440	66
Solar flux	6.5	108	16
Planetary flux	6.5	108	16
Aureole	39.6	-	99
Nephelometer	40.7	680	102
Shock layer* radiometer	-	-	-
Hygrometer	18.6	-	46.5
Transponder	Continuous		

\* 4000 bits storage (for shock layer radiometer plus accelerometer data prior to descent phase)

TABLE 3-6. ATLAS/CENTAUR LARGE PROBE NOMINAL PAYLOAD  
(APRIL)

Instrument	Mass <sup>(1)</sup>		Volume <sup>(2)</sup>		Average <sup>(3)</sup> Power, W	Data <sup>(4)</sup> Rate bps	Comments
	kg	lb	cm <sup>3</sup>	in <sup>3</sup>			
Temperature gauge	0.3	0.65	100	6	0.5	1	Single instrument
Pressure gauge	0.4	0.9	115	7	0.5	1	Single instrument
Accelerometers	1.15	2.5	655	40	2.3 + 8 mW/g	3	Three axis plus one backup Requires data storage during high speed entry
Neutral mass spectrometer	9.07	20.0	9830	600	12.0	40	--
Solar radiometer	2.25	5.0	1600	100	4.0	7/4	Data rate above ~44 km = 7 bps, below ~44 km = 4 bps Single window or light pipe bundle at probe equator
Cloud particle size analyzer	3.65	8.0	3275	200	20.0	24	--
IR flux radiometer	2.25	5.0	1600	100	3.0	3	Single down-looking window
Gas chromatograph	3.6	8.5	4100	250	6.0	11 (Avg.)	Three measurement cycles at 20 min each
Hygrometer	0.5	1.1	330	20	0.25	0.5	Operating range: deployment to ~40 km
Wind altitude radar	4.0	8.8	8195	500	40.0	2	Operating range: ~40 km to surface
Total science payload	27.2	60.45	29800	1823	88.55	70.5/67.5	

(1) Nominal mass shown; assume tolerance of +15, -10 percent

(2) Nominal volume shown; assume tolerance of  $\pm$  15 percent

(3) Nominal average power shown; assume tolerance of +20, -10 percent

(4) Typical data rate for 70 to 80 min terminal descent with chute jettison 40 to 45 km

See Table 3-34 for details

TABLE 3-7. ATLAS/CENTAUR LARGE PROBE  
OTHER CANDIDATE INSTRUMENTS

Instrument	Mass <sup>(1)</sup>		Volume <sup>(2)</sup>		Average <sup>(3)</sup> Power, W	Data <sup>(4)</sup> Rate, bps	Remarks
	kg	lb	cm <sup>3</sup>	in <sup>3</sup>			
X-ray fluorescence	2.25	5.0	2950	180	2.0	9	Requires data storage during high speed entry
ATR spectrometer	2.5	5.5	1500	92	5.0	36	
Aureole detector	2.0	4.5	2460	150	2.5	16	
Shock layer radiometer	1.14	2.5	434	26.5	1.0	N/A	

(1) Nominal mass shown; assume tolerance of +15 percent, -10 percent

(2) Nominal volume shown; assume tolerance of  $\pm 15$  percent

(3) Nominal average power shown; assume tolerance of +20 percent, -10 percent

(4) Typical data rate for 70 to 80 min terminal descent, with chute jettison 40 to 45 km

Two new experiments have been added: the gas chromatograph and the wind altitude radar; however, three have been deleted:\* the aureole detector, nephelometer, and shock layer radiometer. The aureole detector and shock layer radiometer now appear as other candidate instruments, along with the X-ray fluorescence instrument and the ATR spectrometer, as shown in Table 3-7. Of the four instruments previously listed as other candidate instruments, the noise detector and spherics detector have been deleted, and the wind drift radar has moved up to become a nominal instrument. Only the X-ray fluorescence instrument remains from the previous list.

### Small Probe

The Thor/Delta nominal science payload for the small probe is shown in Table 3-8, with the initial Atlas/Centaur figures shown in parentheses where different. The six instruments carried were: temperature sensor pressure sensor, nephelometer, accelerometer, magnetometer, and stable oscillator. Total payload mass was 2.2 kg (4.9 lb). The Atlas/Centaur payload was slightly larger: 2.9 kg (6.3 lb).

Data rate and geometry requirements are shown in Table 3-9. The basic data rate requirement, given in bits/sample, and samples/min, has been converted to an average bits/sec rate. The measurement objective for each experiment is shown in Table 3-10, and also the number of samples obtained in each atmospheric scale height, for the specified sampling rate. The scale heights are defined in Figure 3-9, which shows the small probe descent profile. The three small probes had entry angles ranging from -70.4 to -23.3 deg; however, the descent profiles do not differ significantly from that shown, which is for -70.4 deg.

The Hughes design provided a greater sampling rate capability than required, as shown in Table 3-11. The most significant increase gave added capability to the nephelometer. Samples/km are shown in Figure 3-10.

The current Atlas/Centaur nominal payload is shown in Table 3-12. The payload mass has been reduced back to the Thor/Delta value of 2.2 kg (4.9 lb). The magnetometer has been deleted and an IR flux detector added. The magnetometer now appears as an other candidate instrument, along with an rf altimeter, as shown in Table 3-13. Previously, there were no other candidate instruments listed for the small probe.

### Probe Bus

The Thor/Delta nominal science payload for the probe bus is shown in Table 3-14, with the initial Atlas/Centaur figures shown in parentheses where different. Five instruments were carried: neutral mass spectrometer, ion mass spectrometer, Langmuir probe, uv fluorescence, and magnetometer.

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\*The transponder was deleted by error from the specified payload, being considered part of the communications system. It is still present in the large probe.

TABLE 3-8. THOR/DELTA SMALL PROBE SCIENCE PAYLOAD  
(DECEMBER)

Instrument	Mass		Average Power, W	Volume	
	kg	lb		cm <sup>3</sup>	in <sup>3</sup>
Temperature sensing system	0.34 (0.4)	0.75 (0.9)	0.5	98 (164)	6.0 (10)
Pressure sensing system	0.41	0.9	0.5 (0.75)	115 (164)	7.0 (10)
Nephelometer	0.45 (0.8)	1.0 (1.4)	1.0 (2)	377 (574)	23.0 (35)
Accelerometer	0.18	0.4	1.0	33 (49)	2.0 (3)
Magnetometer	0.50 (0.6)	1.1 (1.2)	1.0 (1.2)	213	13.0
Stable oscillator	0.34 (0.8)	0.75 (1.5)	0.25 (2.0)	131 (492)	8.0 (30)
Total science payload	2.22 (2.86)	4.9 (6.3)	4.25 (7.45)	967 (1656)	59.0 (101)

Comment: ( ) = Initial Atlas/Centaur values if different from Thor/Delta

TABLE 3-9. THOR/DELTA SMALL PROBE SCIENCE PAYLOAD  
GEOMETRY AND DATA RATE REQUIREMENTS

Instrument	Geometry Requirements	Data Requirements		
		Bits /Sample <sup>(1)</sup>	Samples /Min	Bits/Sec <sup>(2)</sup>
Temperature sensing system	Mount in area of large, smooth mass flow	10	3	0.6
Pressure sensing system	Place inlet port at stagnation point	10	3	0.6
Nephelometer	Field of view 15 to 20 deg and requires minimum view of boundary layer and wake	50	2	1.8
Accelerometer	Locate at c. g. with 0.017 deg alignment to spin axis			
Entry and blackout		10	60.0	10.0
Descent		10	3	0.5
Turbulence measurements		7	4.3	0.5
Seismic		10	60.0	10.0
Magnetometer	Must be aligned within 2 deg of spin axis.	24	2.0	0.9

1) Science data only

2) Science and science engineering data

TABLE 3-10. SMALL PROBE DESCENT MEASUREMENTS  
(REQUIRED SAMPLING RATE)

Instrument	Measurement Objective	Samples/ min.	Samples/Scale Height*							
			1	2	3	4	5	6	7	8
Temperature	Temperature profile	3	114	54	30	12	6	1	-	-
Pressure	Pressure profile	3	114	54	30	12	6	2	-	-
Nephelometer	Presence of clouds	2	76	36	20	8	4	1	-	-
Accelerometer* Turbulence	Deceleration history, turbulence	3	114	54	30	12	6	2	-	-
		4.3	163	77	43	17	9	3		
Magnetometer	Planetary magnetic field	2	76	36	20	8	4	1	-	-
Stable oscillator	Wind velocity	Continuous								

\*For baseline trajectory



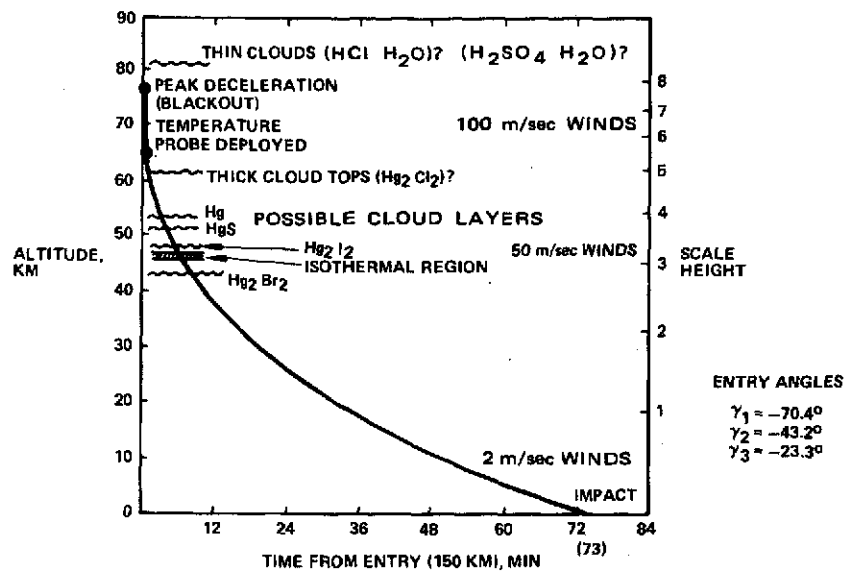


FIGURE 3-9. SMALL PROBE DESCENT PROFILE

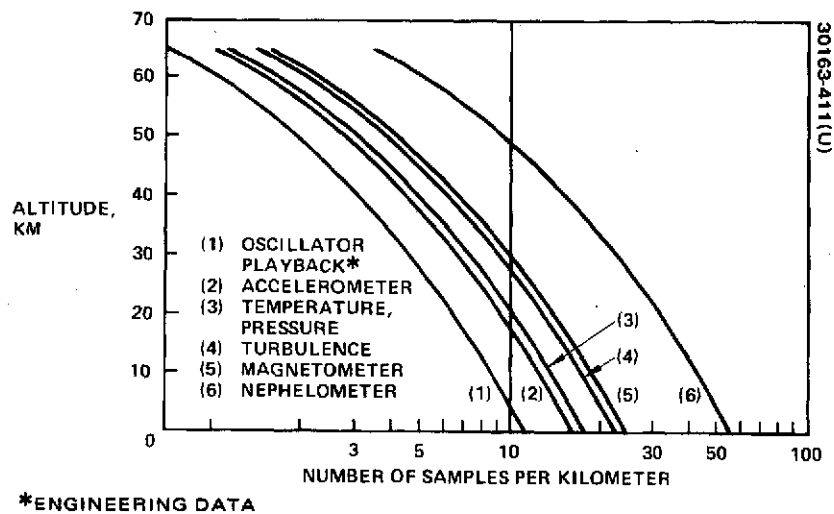


FIGURE 3-10. SMALL PROBE SCIENCE RETURN

TABLE 3-11. SMALL PROBE SCIENCE MEASUREMENTS  
(CAPABILITY PROVIDED)

Instrument	Samples/Min	Samples/Scale Height							
		1	2	3	4	5	6	7	8
Temperature	6.6	251	119	66	26	13	2	-	-
Pressure	6.6	251	119	66	26	13	4	-	-
Nephelometer	20.4	775	367	204	82	4	10	-	-
Accelerometer*	6.0	228	108	60	24	12	4	-	-
Turbulence	8.6	326	154	86	34	18	6	-	-
Magnetometer	9.0	342	162	90	36	18	5	-	-
Stable oscillator	Continuous								

\* 512 bits storage provided for entry and blackout data.

TABLE 3-12. ATLAS/CENTAUR SMALL PROBE NOMINAL PAYLOAD  
(APRIL)

Instrument	Mass <sup>(1)</sup>		Volume <sup>(2)</sup>		Average <sup>(3)</sup> Power, W	Data <sup>(4)</sup> Rate bps	Comments
	kg	lb	cm <sup>3</sup>	in <sup>3</sup>			
Temperature gauge	0.3	0.65	100	6.0	0.5	--	Single instrument
Pressure gauge	0.4	0.9	115	7.0	0.5	--	Single instrument
Accelerometer	0.18	0.4	33	2.0	1.0+ 8 mW/g	--	Single axis Requires data storage during high speed entry
IR flux detector	0.5	1.2	328	20.0	1.0	--	Requires single window in aft housing and deployable mirror mount
Stable oscillator	0.34	0.75	131	8.0	0.25	--	
Nephelometer	0.45	1.0	524	32.0	1.0	--	Requires single window in aft housing
Total science payload	2.2	4.9	1231	75.0	4.25	--	

(1) Nominal mass shown; assume tolerance of +15, -5 percent

(2) Nominal volume shown; assume tolerance of  $\pm 15$  percent

(3) Nominal average power shown; assume tolerance of +20, -10 percent

(4) See Table 3-39 for details

TABLE 3-13. ATLAS/CENTAUR SMALL PROBE,  
OTHER CANDIDATE INSTRUMENTS

Instrument	Mass <sup>(1)</sup>		Volume <sup>(2)</sup>		Average <sup>(3)</sup> Power, W	Data Rate, bps	Remarks
	kg	lb	cm <sup>3</sup>	in <sup>3</sup>			
RF altimeter	0.45	1.0	229	14.0	4.6	1.0	Operates from ~ 50 km to surface
Magnetometer	0.45	1.0	197	12.0	1.0	1.7	Requires data storage during high speed entry

(1) Nominal mass shown; assume tolerance of +15, -10 percent

(2) Nominal volume shown; assume tolerance of ±15 percent

(3) Nominal average power shown; assume tolerance of +20, -10 percent

TABLE 3-14. THOR/DELTA PROBE BUS SCIENCE PAYLOAD  
(DECEMBER)

Instrument	Mass		Average Power, W	Volume	
	kg	lb		cm <sup>3</sup>	in <sup>3</sup>
Neutral mass spectrometer	5.0 ( 5.4)	11.0 (12.0)	5.9 (12.0)	5735 ( 8190)	350 ( 500)
Ion mass spectrometer	1.4 ( 1.5)	3.0 ( 3.2)	2.0	3930	240
Langmuir probe	1.6	3.5	2.0 ( 2.5)	1820	111
Ultraviolet fluorescence	1.4 ( 1.6)	3.0 ( 3.5)	2.5 ( 4.0)	1965	120
Magnetometer	2.3 ( 2.5)	5.1 ( 5.5)	3.5 ( 4.0)	4310	263
Total science payload	11.6 (12.6)	25.6 (27.7)	15.9 (24.5)	17760 (20220)	1084 (1234)

Comment: ( ) = Initial Atlas/Centaur values if different from Thor/Delta

TABLE 3-15. THOR/DELTA PROBE BUS SCIENCE PAYLOAD  
DATA RATE AND GEOMETRY REQUIREMENTS

Instrument	Data Requirements			Geometry Requirements
	Bits/ Sample*	Samples/ Min	Bits/ Sec**	
Neutral mass spectrometer	2500	2	84	Inlet port opens parallel to velocity vector
Ion mass spectrometer	2000	2	67	Inlet port opens parallel to velocity vector
Langmuir probe	32	60	32	90 degrees to spin axis
Ultraviolet fluorescence	72	20	24	Diffraction grating must be aligned to within 0.05 degree. If doppler scanning of absorption line is to be done, velocity vector should be at $10 \pm 1$ degree to spin axis, and boom supporting the diffraction grating should be canted forward 10 degrees
Magnetometer	32	20	14	Alignment to spin axis $\pm 2$ degrees

\* Science data only

\*\* Science and science engineering data

Payload mass was 11.6 kg (26.6 lb). The Atlas/Centaur payload was slightly larger: 12.6 kg (27.7 lb).

Data rate and geometry requirements are shown in Table 3-15. The basic data rate requirement, given in bits/sample and samples/min, has been converted to an average bits/sec rate. Total data rate was 220 bps.

The measurement objective for each experiment is shown in Table 3-16. Also shown are the required sampling rate and the capability actually provided, which is a factor of 10 higher. This high sampling rate is highly desirable because of the very short observation times in the altitude region of most interest. Figure 3-11 shows the probe bus entry profile, from an altitude of about 1000 km to burnup at about 120 km. Figure 3-12 shows samples per scale height for the nominal sampling rate, and it is seen that at the lower scale heights, a very small number of samples were obtained. With the factor of 10 increased capability provided, at least one sample per scale height was provided for each instrument.

The current Atlas/Centaur nominal payload is shown in Table 3-17. Its mass is intermediate between the Thor/Delta and initial Atlas/Centaur values, 12.0 kg (26.4 lb). The data rate specified is now 1640 bps. The uv fluorescence experiment and the magnetometer have been deleted. A uv spectrometer and a retarding potential analyzer have been added. The magnetometer has become another candidate instrument, as shown in Table 3-18. Previous other candidate instruments were a solar wind probe and a uv photometer.

TABLE 3-16. PROBE BUS ENTRY MEASUREMENTS

Instrument	Objective	Samples/Min		Altitude Range
		Required	Capability Provided	
Neutral mass spectrometer	Measure number density of selected constituents of upper atmosphere; H, He, O, CO, N <sub>2</sub> , Ar, CO <sub>2</sub>	2	20	1000 km to bus burnup
Ion mass spectrometer	Measure number density of selected thermal ions in upper atmosphere; H <sup>+</sup> , D <sup>+</sup> , He <sup>+</sup> , O <sup>+</sup> , CO <sup>+</sup> , NO <sup>+</sup> , O <sub>2</sub> <sup>+</sup> , CO <sub>2</sub> <sup>+</sup>	2	20	5000 km to bus burnup
Langmuir probe	Measure temperature and number density of ionosphere thermal electrons	60	600	5000 km to bus burnup
UV fluorescence	Measure amount of O and CO in upper atmosphere (backup to neutral mass spectrometer)	20	200	1000 km to bus burnup
Magnetometer	Measure magnetic profile through solar wind bow shock, sheath, plasmopause, and ionosphere	20	200	Cruise to bus burnup



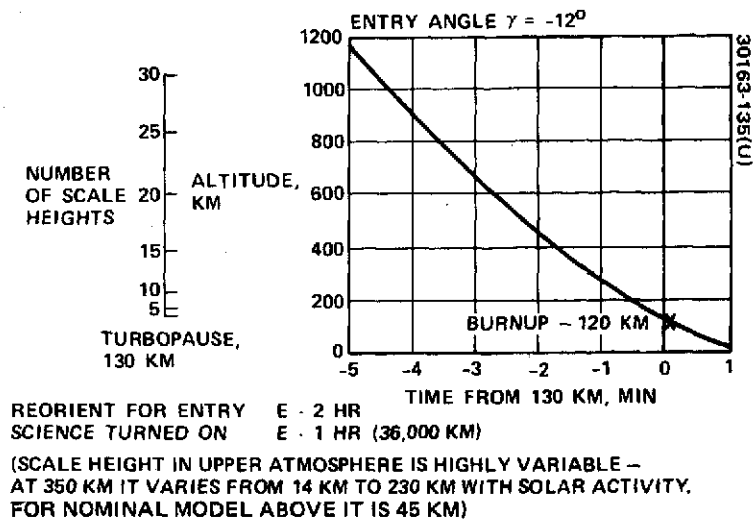
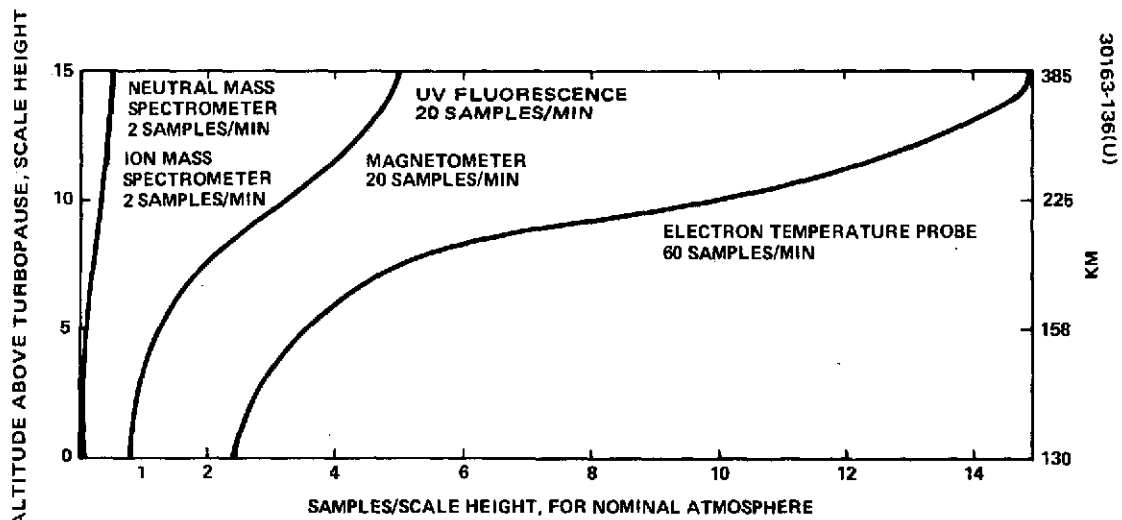


FIGURE 3-11. PROBE BUS ENTRY



NOTE: FOR BASELINE DESIGN MULTIPLY BY 10

FIGURE 3-12. PROBE BUS MEASUREMENTS

TABLE 3-17. ATLAS/CENTAUR PROBE BUS NOMINAL PAYLOAD  
(APRIL)

Instrument	Mass <sup>(1)</sup>		Volume <sup>(2)</sup>		Average <sup>(3)</sup> Power, W	Data <sup>(4)</sup> Rate, bps	Remarks
	kg	lb	cm <sup>3</sup>	in <sup>3</sup>			
Neutral mass spectrometer	5.5	12.0	8195	500	12.0	360	-
Ion mass spectrometer	1.6	3.5	2459	150	2.5	450	-
Electron temperature probe	1.0	2.2	1500	91.5	3.0	70	-
UV spectrometer	2.7	6.0	2295	140	1.5	12/500	12 bps from entry- minus-4 days to entry-minus-1 h, 500 bps from entry- minus-1 h
Retarding potential analyzer	1.2	2.7	1967	120	2.5	260	-
Total science payload	12.0	26.4	16420	1001.5	21.5	1152/1640	-

(1) Nominal mass shown; assume tolerance of +15, -5 percent

(2) Nominal volume shown; assume tolerance of  $\pm 15$  percent

(3) Nominal average power shown; assume tolerance of +20, -10 percent

(4) Typical data rates for entry angle of -20 degrees (1977 mission)  
See Table 3-44 for details

TABLE 3-18. ATLAS/CENTAUR PROBE BUS  
OTHER CANDIDATE INSTRUMENTS

Instrument	Mass <sup>(1)</sup>		Volume <sup>(2)</sup>		Average <sup>(3)</sup> Power W	Data Rate, bps	Remarks
	kg	lb	cm <sup>3</sup>	in <sup>3</sup>			
Solar wind analyzer	1.36	3.0	2100	128	2.5	58	Cruise and entry measurements
Magnetometer	2.25	5.0	3934	240	3.0	15/30	15 bps for cruise 30 bps from entry-minus-1 h

(1) Nominal mass shown; assume tolerance of +15, -5 percent

(2) Nominal volume shown; assume tolerance of ±15 percent

(3) Nominal average power shown; assume tolerance of +20, -10 percent

TABLE 3-19. STUDY TASK SUMMARY

Task No.	S/W* Reference No.	Experiment Integration Tasks	Completion Date
EX1	2. 2. 1. 1	Payload tradeoff analysis	5/16/73
EX2	2. 2. 1. 2	Payload design integration	P11/15/72** F6/1/73
EX3	2. 2. 1. 3a	Determine probe optical window material, sizes, and location (transferred to PB39)	3/20/73
EX4	2. 2. 1. 3b	Evaluate approaches to prevent optical window condensation and contamination (transferred to PB39)	3/30/73
EX5	2. 2. 1. 4	Experiment external location and deployment (transferred to PB29)	5/2/73
EX6	2. 2. 1. 5a	Mass spectrometer inlet design (deleted)	--
EX7	2. 2. 1. 5b	Techniques to prevent condensation in mass spectrometer inlet (deleted)	--
EX8	2. 2. 1. 6	Wind drift radar/altimeter study	5/18/73
EX9	2. 2. 1. 6	Microwave radiometer study (deleted)	--
EX10	2. 2. 1. 7	Externally mounting upper atmosphere sensors	3/28/73
EX11	2. 2. 1. 8	External sensors alignment/stability study	4/16/73
EX12	2. 2. 1. 9	Spin axis orientation/science requirements	12/15/72
EX13	2. 2. 1. 10	Sensor viewing and location (now part of EX2)	--
EX14	--	Probe dynamic effects on radar measurements (now part of EX8)	--
EX15	--	Magnetometer studies	1/15/73
EX16	2. 1. 6. 1	General experiment interface specification (transferred to SP4)	6/1/73
EX17	2. 1. 6. 2	Detail experiment interface specifications for selected experiments (deleted)	--
EX18	2. 1. 6. 3	Interface control drawings for experiments (deleted)	--
EX19	2. 1. 10	Experiment integration plan (transferred to PL10)	6/1/73

\*S/W = Statement of Work

\*\*P = Preliminary  
F = Final

### 3.3 TRADEOFF STUDIES

At the beginning of the Pioneer Venus study, a number of study tasks relating to experiment accommodation were defined, based primarily on the RFP statement of work, but including additional tasks that Hughes felt were important for the system design. These tasks are listed in Table 3-19, and referenced to paragraphs in the statement of work where appropriate. Most tasks were scheduled for early completion so that attention could then be turned toward specifications and plans.

Some of these initial tasks were transferred from the experiment integration area to other areas of primary responsibility, e.g., optical window studies (EX3, EX4) and external sensor location studies (EX5) to the probe design area; some were deleted, e.g., the mass spectrometer inlet studies (EX6, EX7) and the microwave radiometer study (EX9), with NASA/ARC concurrence, as the study ground rules changed; and some were combined with other study tasks, e.g., sensor viewing and location (EX13) with payload design integration (EX2), and probe dynamic effects on radar measurements (EX14) with the wind-drift radar/altimeter study (EX8), which still later was broadened in scope to be a wind velocity measurement study.

Listed at the bottom of Table 3-19 are some general tasks relating to experiments, namely: a general experiment interface specification (EX16), transferred to the specification area as SP4; two detailed experiment interface tasks (EX17, EX18), deleted after discussions with NASA/ARC indicated they will prepare such documents; and an experiment integration plan (EX19), transferred to the preliminary development plans area as PL10.

Those tasks relating to the multiprobe mission will be summarized in this section, even if carried out in other areas. Table 3-20 lists these tasks with a brief statement of task objective. The tradeoff studies were carried out primarily for the Thor/Delta launch vehicle. Their applicability to Atlas/Centaur is indicated at the end of each task. Many study tasks from other areas interact with the experiment task studies. These will be noted as pertinent. The most appropriate order to discuss the study tasks is not the order in which they are numbered. Thus, the following sections do not follow the task numbering system.

#### Payload Design Integration (EX2)

The most important single task in the experiments area was the payload design integration task. Primary output was the Experiment Engineering Data Book, which gathered together information on each Pioneer Venus instrument in the standard format shown in Table 3-21.

Both a Thor/Delta and an Atlas/Centaur version of the Experiment Data Book were prepared, and served as the standard reference for experiment data for all areas of the Pioneer Venus study. A copy of this book is being issued as the study task report on EX2. To provide an example of the material presented, a typical instrument write-up, covering the accelerometers for the large probe, is included as Supplement 3-1.

TABLE 3-20. EXPERIMENT INTEGRATION TASK OBJECTIVES  
(MULTIPROBE MISSION)

EX1: Payload Tradeoff Analysis

Study accommodation of the other candidate instruments in addition to the nominal payload.

EX2: Payload Design Integration

Identify and resolve payload accommodation problems by understanding the instrument and science requirements and relating them to integration requirements.

PB39: Experiment Window Design (EX3, EX4)

Develop preliminary design approaches for the selection of pressure vessel window materials and mechanical design of the window, anti-condensation heaters, and a particulate contamination removal system.

PB29: Experiments/Structure Interaction Design Study (EX5)

Develop preliminary design approaches for handling all penetrations of the small and large probe pressure vessels.

EX8: Wind Drift Radar/Altimeter Study

Define and study wind drift radar requirements and implications on probe design, including trajectory and dynamics factors, as well as physical integration of the radar antenna.

EX10: Externally Mounting Upper Atmosphere Sensors

Evaluate system tradeoffs, weight savings, aerodynamic complexity, volume efficiency, if some of the upper atmosphere sensors are externally mounted.

EX11: External Sensors Alignment/Stability Study

Evaluate alignment and stability of critical external or protruding sensors on the probes to ensure meeting science requirements.

EX15: Magnetometer Studies

Determine requirements and locations for the magnetometers on the small probes, probe bus, and orbiter.

SP4: Experiment Interface Specification (EX16)

Define the overall system and subsystem interfaces that the experimenters must meet

PL10: Experiment Integration Plan (EX19)

Define the plans and procedures for managing experiment integration activities.

TABLE 3-21. PIONEER VENUS EXPERIMENT DATA BOOK FORMAT

1.0	Experiment name
2.0	Applicable documents
3.0	Scientific purpose of experiment
4.0	Experiment description and operation
5.0	Mechanical and thermal interface
	Weight and mass properties, size, mounting position, sensor orientation and field of view, thermal properties
6.0	Electrical interface
	Power, commands, telemetry, electrical connectors
7.0	Special requirements
	Ordnance devices, electromagnetic, magnetic, radioactive sources, cleanliness, handling, and storage
7.0	System and mission requirements
	Orbit parameters (if applicable), mission scenario, geometric parameters, targeting parameters, scanning/ tracking parameters
	Outline and mounting drawing
	Block diagram
	Electrical interface drawing

TABLE 3-22. SPECIAL EXPERIMENT REQUIREMENTS IMPACTING  
LARGE PROBE DESIGN

Instrument	Special Requirements	Implementation
Temperature gauges	Extend beyond boundary layer	Forward hemisphere location ( $\pm 60^\circ$ from spin axis)
Pressure gauges	Port at probe stagnation point	Forward hemisphere location ( $\pm 30^\circ$ from spin axis)
Accelerometers	C. G. location with accurate alignment	At c. g. with $0.017^\circ$ alignment to spin axis
Neutral particle mass spectrometer	Location of inlet system requires large number of squib firing devices.	Large inlet (7.6 cm) located $45^\circ$ from descent axis, protruding beyond boundary layer
Cloud particle size analyzer	Externally mounted mirror aligned to 1 mr	Mirror located on 15 cm (6 in.) struts in integral mount
Solar radiometer	Up and down viewing	Separate sensors internal
IR flux detector	Downward viewing	Internal mount viewing parallel to descent
Aureole extinction detector	Sun scanning	Probe spin with sun scanning
Transponder	None	(Assumed contractor provided)
Nephelometer	Large scattering angle between source and detector	Sensor widely separated from light source
Shock layer radiometer	Viewing entry shock wave at stagnation point	Sensor in heat shield
Hygrometer	Externally positioned sensor	Midhemisphere location, extending beyond boundary layer



Tables 3-22, 3-23, and 3-24 summarize the special experiment requirements which impacted the large probe, small probe, and probe bus designs for both the Thor/Delta and the initial Atlas/Centaur payload.

#### Experiment Window Design (PB39)

This study covered selection of window materials, window mechanical design, window heater design, and contaminant removal. A number of window materials were evaluated, resulting in selection of baseline materials for windows operating in the visible and infrared regions of the spectrum. Preliminary designs of windows, window heaters, and contaminant removal systems were developed in great enough detail to allow meaningful comparisons between items such as mass, power consumption and development risk. These figures were used in trade studies, the results of which were evaluated to yield recommended baseline approaches in each area.

#### Window Material Selection

Selection of materials for descent probe pressure vessel windows is limited to those capable of withstanding the Venus surface temperature and pressure environment, and is further constrained by considerations of abrasion resistance, in-band emissivity as a function of temperature, high temperature transmission, and low internal scattering.

For windows operating in the visible region of the spectrum, sapphire ( $\text{Al}_2\text{O}_3$ ) and fused silica ( $\text{SiO}_2$ ) were studied, resulting in the selection of sapphire as a baseline material because of its superior abrasion resistance (1600-2200 Knoop hardness, as opposed to approximately 500 Knoop for silica), and high temperature tensile strength (at 500°C, sapphire has a tensile strength of 40,000 psi compared to approximately 10,000 psi for fused silica).

For windows operating in the infrared region of the spectrum, a comparison between IRTRAN II (ZnS), IRTRAN IV (ZnSe) and chemically vapor deposited ZnSe (CDV ZnSe) has resulted in selection of CDV ZnSe as a baseline material because of its superior long wavelength transmission characteristics (out to 14  $\mu\text{m}$ ) compared to IRTRAN IV and ZnS and its extremely low in-band emissivity at high temperatures.

#### Window Mechanical Design

A primary problem in window mechanical design is achieving a seal between the window and the pressure vessel capable of withstanding Venus surface temperatures. Metallic O-rings were studied as one seal method; also studied was brazing the windows to a kovar or invar collar which in turn would be bolted to the pressure vessel wall. As a result of these studies, O-ring type seals are recommended at all interfaces with the pressure vessel wall, while brazing is recommended for windows mounted remotely from the pressure vessel.

TABLE 3-23. SPECIAL EXPERIMENT REQUIREMENTS IMPACTING  
SMALL PROBE DESIGN

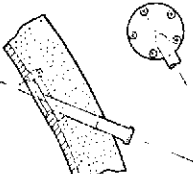
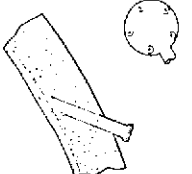
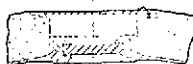
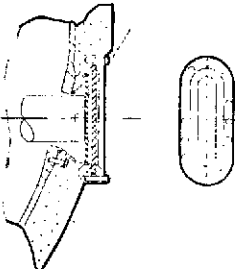
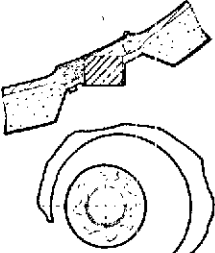
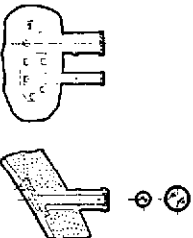
Instrument	Special Requirements	Implementation
Temperature gauge	Deployable gauge	Swing type on aft step of heat shield
Pressure gauge	Port at stagnation point	Pressure tube through heat shield, ejectable cover
Nephelometer	Clear window viewing 90° to descent axis	Heated and protected window, above aft step, viewing 90° to axis
Accelerometer	C.G. location with accurate alignment	At c. g. with 0.017° alignment to axis
Magnetometer	Background of less than 100 $\gamma$ , axial rotation	Careful positioning, magnetic control, probe spin
Stable oscillator	Close thermal control to maintain stability	Accurate temperature monitoring

TABLE 3-24. SPECIAL EXPERIMENT REQUIREMENTS IMPACTING  
PROBE BUS DESIGN

Instrument	Special Requirement	Implementation
Neutral mass spectrometer	Velocity pointing	Mounted parallel to spin axis*
Ion mass spectrometer	Velocity pointing	Mounted parallel to spin axis*
Electron temperature probe	Negative polarity solar panel	Coating solar panel surface with insulating material
UV fluorescence	Grating on end of boom perpendicular to velocity vector	0.5 m (20 in.) deployed boom perpendicular to spin axis* (boom provided by experimenter)
Magnetometer	5 $\gamma$ background	1.1 m (42 in.) deployed boom, magnetic control

\*Spin axis close to velocity vector on entry

TABLE 3-25. SUMMARY OF BASELINE WINDOW CONFIGURATION CHARACTERISTICS

		Instruments					
		Nephelometer Source	Nephelometer Sensor	Aureole Extinction Detector	Solar Radiometer	Planetary Flux Radiometer	Cloud Particle Size Spectrometer
Configuration							
Window Characteristics	Quantity	1	1	1	1	1	2
	Field of view	1 deg conical	5 deg conical	In vertical plane $\pm 15$ deg In horizontal plane $\pm 1/2$ deg	In vertical plane $\pm 60$ deg In horizontal plane $\pm 15$ deg	5 deg conical	1.3 cm (0.50 in.) constant diameter 0.64 cm (0.25 in.)
	Aperture size	0.64 cm (0.25 in.) diameter	1.3 cm (0.50 in.) diameter	2.5 cm (1.0 in.) diameter	Vertical 5.1 cm (2.0 in.) Horizontal 1.3 cm (0.50 in.)	2.5 cm (1.0 in.) diameter	1.3 cm (0.50 in.) diameter 0.64 cm (0.25 in.)
	Window material	Sapphire	Sapphire	Sapphire	Sapphire	CVD ZnSe*	Sapphire
	Long wave cutoff	3.5	3.5	3.5	3.5	13.5	3.5
	Type heater	Sheathed element	Sheathed element	Film heater - outer window only	Sheathed element	Sheathed element (if required)	Sheathed element
	Heater power	2 W	6 W	4 W (Off at 40 km)	22 W	18 W	8 W (total)
	Type seal	Braze	Braze	O-ring	O-ring	Braze	Braze
	Window assembly mass	4.5 g (0.01 lb)	18 g (0.04 lb)	82 g (0.18 lb)	118 g (0.26 lb)	141 g (0.31 lb)	45 g (0.10 lb)
	Contamination removal	Jettisonable cover	Jettisonable cover	Jettisonable cover	Jettisonable cover	Jettisonable cover	Jettisonable cover
	Comments	Lightest weight configuration examined. Remote mounting for window thermal isolation	Window larger than source window to accommodate wider field of view. Same general configuration	Space between inner and outer window hermetically sealed	O-ring seal used to provide increased thermal isolation for window	Thick window due to low modulus of rupture of IR transparent window material	Dual window configuration is lightest configuration and uses the least heater power of those examined

\*Chemically vapor deposited zinc selenide

Thermal considerations in window design include minimizing power required to heat the window and minimizing the "heat leaks" from the windows to the interior of the probe. Approaches used to achieve these goals by minimizing thermal conductivity from the window to the pressure vessel interior include: mounting windows on stalks away from the pressure vessel wall; use of low-conductivity washers to support the window; and use of a double window configuration to reduce convection and radiation to the probe interior.

Structural considerations include window structural integrity and the influence of penetrations on pressure vessel buckling strength. Window diameter is determined by science requirements, and thickness is then sized to provide a safety factor of four at Venus surface temperatures and pressures. Reductions in pressure vessel buckling strength by penetrations are prevented by locally increasing the wall thickness in the region surrounding the penetration.

Producibility of pressure vessel shells incorporating reinforced penetrations was studied to determine the most cost effective means of fabrication. Electron beam welding of axially symmetric plugs which incorporate the doubler configuration into a shell of uniform thickness has been selected as a baseline fabrication method. The cost of this approach is low with respect to integral machining of shell and doublers, and its effect on pressure vessel structural integrity is minimal. Evaluation of bonded doublers is also continuing pending better definition of pressure vessel wall temperatures. No other difficulties are anticipated in fabrication of window configurations typical of those studied. Table 3-25 shows the baseline window configurations chosen for each experiment.

#### Window Heater Design

Preliminary analyses using the baseline windows as models have been performed to define heater power requirements. At Venus surface conditions the 0.64 cm (0.25 in.) diameter windows of the nephelometer require 6 w each. The 2.5 cm (1.0 in) diameter windows of the cloud particle size analyzer and the planetary flux radiometer require 12 w and the 5.1 cm (2.0 in.) oval window for the solar flux radiometer requires 20 w. Heater power scheduling methods studied were: 1) using a controller to keep the windows at a set temperature differential with respect to ambient; 2) turning the heaters on at full power when the aft cover is jettisoned; and 3) using two power levels, initiating low power mode when the aft cover is jettisoned and switching to high power at parachute release. As a result of these studies the single power level approach was determined to be a minimum mass system and was selected as a baseline.

Three window heater configurations were studied for windows exposed to the full differential between Venus atmosphere ambient and probe internal pressures: 1) film heaters using a thin layer of a proprietary conductor deposited on the window surface; 2) heating elements consisting of thin wires sandwiched between layers of sapphire. Grooves would be etched into the surface to mechanically retain the heating elements; 3) edge heating by means

of electrical heating elements wrapped around the window periphery in direct contact with the window edge; and 4) edge heating by means of electrical heating elements enclosed in a metallic sheath which contacts the window edge.

An evaluation of these configurations led to rejection of the film heater for pressure windows for reasons of power density and the difficulty of integrating electrical contacts into the small window sizes used. The "sandwich" heater approach is an efficient system, but the extra thickness of sapphire required as a retainer (the pressure window must retain its full thickness, as no bonding material can exist at the required temperatures to form the two windows into an integral structure), as well as the unavoidable optical losses at the extra interface, led to rejection of this approach. Bare electrical heating elements represent the highest efficiency for edge heater configurations, and are potentially the lowest mass method, but fundamental difficulties in maintaining electrical isolation in extremely compact window configurations and at the high temperatures under investigation as well as generation of stray magnetic fields make this a high risk approach. Heating elements enclosed in a metallic sheath and heating the window around its periphery were selected as a baseline because they are well developed, space qualified, and available in a wide variety of shapes and power ratings, yielding a very flexible and low risk approach. In addition, the bifilar nature of the heating element current flow eliminates stray magnetic fields.

For nonpressure windows, with their much smaller ratio of thickness to diameter, film heaters save considerable power compared to edge heating, resulting in the selection of film heaters as a baseline configuration for all external windows operating in the visible range.

#### Contaminant Removal

Window contaminants of particulate nature (dust, sand, liquid droplets) could significantly degrade experiment data. Accordingly, six candidate methods of contaminant removal have been studied:

- 1) Frangible, squib actuated tempered glass protective covers.
- 2) Transparent, jettisonable protective covers.

Both the preceding methods would have the instruments reading through the cover down to a preset altitude. At this point the covers are either destroyed or jettisoned, removing accumulated contaminants (accumulation of which would be indicated by a sudden change in readings following cover removal).

- 3) Transparent rotary shutter. This shutter could be operated in two modes: rapid continuous rotation (at least several thousand rpm) would sling contaminants off by centrifugal force; alternately, slower, stepped rotation would bring a clear area of shutter into view prior to each reading.

- 4) Mechanical shutter. Solenoid actuated, the shutter minimizes the amount of time that the window is exposed to contamination.
- 5) Mechanical wiper. Also solenoid actuated, the mechanical wiper requires a double window as the wiped window should be flush with the wiper surface. Development of a wiper material capable of providing both effective, nonsmearing wiping action and withstanding the Venus surface environment is a high risk item, but potential effectiveness is very good if such a material can be developed.
- 6) Gas jet. A gas jet system using a squib actuated valve to bleed gas from an internal reservoir to nozzles adjacent to each window requires relatively little development effort and is adaptable to sunken windows; but it is by far the heaviest and bulkiest system considered. An alternate gas jet system using filtered ram air was evaluated and appears attractive because of its low mass and completely passive nature, but considerable testing would be required to determine system effectiveness.

A preliminary analysis has been conducted to yield mass, power consumption and other characteristics for each configuration considered. The results of these studies are summarized in Table 3-26.

On the basis of these studies, jettisonable protective covers are recommended as a baseline contaminant removal system for windows operating in the visible range because of their low mass, low power consumption, and low development risk.


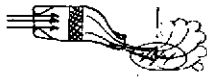
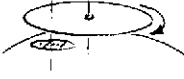




#### Experiments/Structure Interaction Design Study (PB 29)

This study covered development of preliminary design approaches for penetrations of the large and small probe pressure vessels, and umbilical and disconnect devices for the large probe pressure vessel subsystems. Preliminary designs in these areas were developed in great enough detail to allow meaningful comparisons between items such as mass, ease of integration, and development risk. These factors were evaluated in trade studies to yield recommended baseline approaches in each area.

#### Science/Structure Integration: Large Probe

Instruments treated in this section include all those on the large probe requiring direct physical access to the atmosphere of Venus, or which have components mounted outside of the pressure vessel. The mass spectrometer and pressure sensor inlet system fall into the first category, while the condensing mirror of the cloud particle spectrometer and the temperature and hygrometer sensors occupy the second.

TABLE 3-26. COMPARISON OF CANDIDATE CONFIGURATIONS FOR CONTAMINANT REMOVAL SYSTEMS

	Approach						
	Continuously Acting Systems					One-Shot Systems	
	High Pressure Gas Jet	Ram Air Gas Jet	Rotary Shutter	Mechanical Wiper	Mechanical Shutter	Frangible Cover	Jettisonable Cover
Characteristics							
Operation	Fixed nozzle directs gas flow over window, blowing contaminants off	Ram air collected by scoop and filtered, then ducted across window shielding window from contaminants	Rapidly rotating transparent cover slings contaminants off	Wiper mechanically removes contaminants from outer of double window configuration	Mechanical shutter opens only during readings, minimizing window exposure to contaminants	Transparent cover shatters, carrying away accumulated contaminants	Transparent cover jettisoned, carrying away accumulated contaminants
Removes contaminants	Yes	No	No	Yes	No	Yes	Yes
Shields window	Yes	Yes	Yes	No	Yes	Yes	Yes
Effectiveness	Difficult to assess without testing	Very difficult to assess without testing	Potentially good; testing required for evaluation	Potentially excellent if suitable wiper material available	Depends on nature of contaminants. Some protection inherent with respect to unprotected window	Very effective for all types of contamination, but can only be used once	Very effective for all types of contamination but can only be used once
Droplet/particle accumulation	Potentially fair to good	Very difficult to assess without testing	Potentially good	Excellent			
Liquid film	Potentially fair to good	Very difficult to assess without testing	Potentially excellent	Excellent			
Acid etch	Difficult to assess	Very difficult to assess without testing	Cover susceptible	Depends on wiper material and contaminant			
Abrasion	Could increase abrasion (sandblast)	Good	Good, but cover susceptible to abrasion	Could increase abrasion			
Mechanization	Solenoid actuated valve periodically bleed gas from reservoir. Regulator required to lower gas consumption	Completely passive	Electric motor drives rotating disc shaped cover - continuous or stepped rotation	Solenoid sweeps wiper spring return	Solenoid opens shutter against return spring	Squib driven pin impacts cover. Residual stresses in tempered glass cover cause total disintegration	Hot wire initiator unlocks cover which is jettisoned by springs
Mass per window	5.7 kg (12.5 lb)	91 g (0.2 lb)	0.68 kg (1.5 lb)	0.68 kg (1.5 lb)	0.45 kg (1.0 lb)	45 g (0.1 lb)	45 g (0.1 lb)
Commands required	1 squib actuation pulse for system start 1/10 duty cycle pulses for solenoid	None	1 command required system actuation	1/10 duty cycle pulses required for switching power to solenoid	Command required prior to each instrument reading to switch solenoid and open shutter	1 squib actuation pulse required for cover disintegration	1 squib actuation pulse required for cover jettison
Power required for window	Squib pulse plus 7 W average continuous	None	15 W	17 W	13 W	1 squib pulse	1 squib pulse
Relative reliability	Good due to simple mechanization	Very high due to passive nature of system	Potentially low due to complex mechanization	Good, as mechanization is simple redundancy provided by spring return	Good, mechanization very simple. Redundant actuation provided by spring cartridge	Very high due to straightforward mechanization	Very high due to straightforward mechanization
Relative development effort required	Low - primarily testing to evaluate performance and optimize design	High - extensive development required to define system and evaluate performance	High - extensive development required to qualify high temperature motor and drive mechanism	High - development required to define and qualify suitable wiper material	Low - mechanical development limited to high temperature qualification of drive mechanism	Lowest - similar system operational on AF-Hughes "Maverick" missile	Low - mechanization easy to implement
Easily adaptable to different window configurations	Yes	No	No	No	No	Yes	Yes



Mass Spectrometer. Installation of rf quadrupole and double focussing type mass spectrometers was studied; both types require analyzer system installation after the equipment shelf is installed. The rf quadrupole analyzer is inserted from outside the pressure vessel shell and is rigidly mounted to the shell. The double focus mass spectrometer analyzer inlet system is installed from inside the pressure vessel; the pressure vessel wall mounted inlet system is isolated by metallic bellows from the shelf mounted analyzer. Both configurations use metallic O-ring seals at the inlet system/pressure vessel interface (see Figure 3-13).

Cloud Particle Size Spectrometer Mirror Mount. Two mirror support configurations were considered: keeping the mirror support structure integral with the instrument, or mounting the support structure to the pressure vessel wall. The pressure vessel mounted mirror support is lighter, simpler, and easier to integrate; however, due to relative motion between the shelf mounted instrument and the pressure vessel wall this system is not able to satisfy the rigid (1 mr) alignment requirements of the experiment. Accordingly, the instrument mounted mirror support has been chosen as a baseline approach (see Figure 3-14).

Pressure Sensor Inlet System. The primary requirement to be satisfied in design of the inlet system for the pressure sensor is keeping the inlet within 30 deg of the probe stagnation point while minimizing line length to the internal sensor.

Shelf and pressure vessel wall locations for the sensor unit were studied; the wall mounted sensor provides significantly reduced line lengths for the system, and has been chosen as the baseline configuration.

Temperature and Hygrometer Sensor Mounting. Temperature and hygrometer sensors are mounted to brackets which allow installation and checkout of the sensors prior to installation of the probe insulation layer.

#### Science/Structure Integration: Small Probe

The primary additional requirement imposed on small probe external instrumentation is protection from the entry heating pulse. Three experiment components require such protection: the pressure sensor inlet system, the temperature sensor, and the nephelometer window.

Nephelometer Window. The small probe nephelometer window requires a protective cover which can be opened or jettisoned after planetary entry.

Two concepts were examined: a mechanically latched door, activated by a nonexplosive initiator, and a pyrotechnically activated jettisonable cover, using a single bridgewire apollo standard initiator (see Figure 3-15).

Due to the mission critical nature of window protection during entry, the pyrotechnically jettisoned cover is recommended as a baseline because of its inherently fail-safe nature with respect to premature window exposure.

Temperature Sensor. The platinum wire temperature sensor is housed during entry. Deployment after entry is accomplished by a dual spring activated swing arm which is released by redundant hot wire initiators. The length of the arm positions the sensor well into the region of free stream flow after deployment (see Figure 3-16).

Stagnation Point Pressure Sensor Inlet System. The small probe pressure sensor inlet must be located at the probe stagnation point. This requires a penetration in the probe aeroshell and ablator.

Three methods of accomplishing this were evaluated: a passive "survivable" pitot tube using refractory metals and heat sinks to absorb the entry heat pulse; a jettisonable, ablating teflon plug, removed by a pyrotechnically activated, spring driven piston; and a pyrotechnically driven piston cutter which actually cuts an inlet through aeroshell and ablator (see Figure 3-17).

The jettisonable plug approach was selected as baseline because it appears to offer a superior probability of successful post entry deployment. The two other concepts appear highly susceptible to blockage by loose ablative material.

#### Externally Mounting High Altitude Sensors (EX10)

This study covered those experiments of the large and small probes that are not required to operate down to the surface. Instruments were evaluated to see if they might advantageously be mounted external to the pressure vessel. The following instruments were selected for study.

##### Large Probe

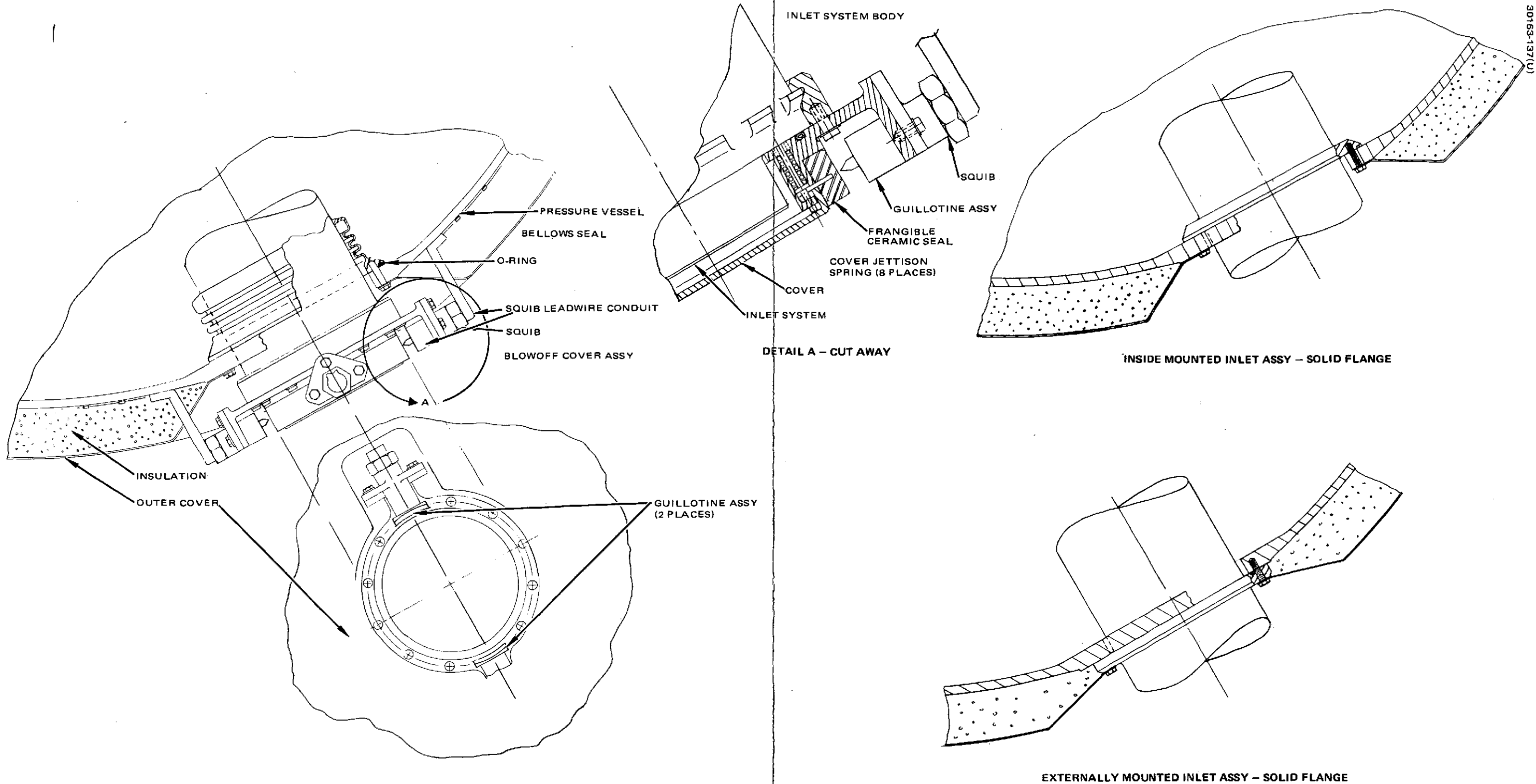
Pressure gauges  
Aureole extinction detector  
Hygrometer

##### Small Probe

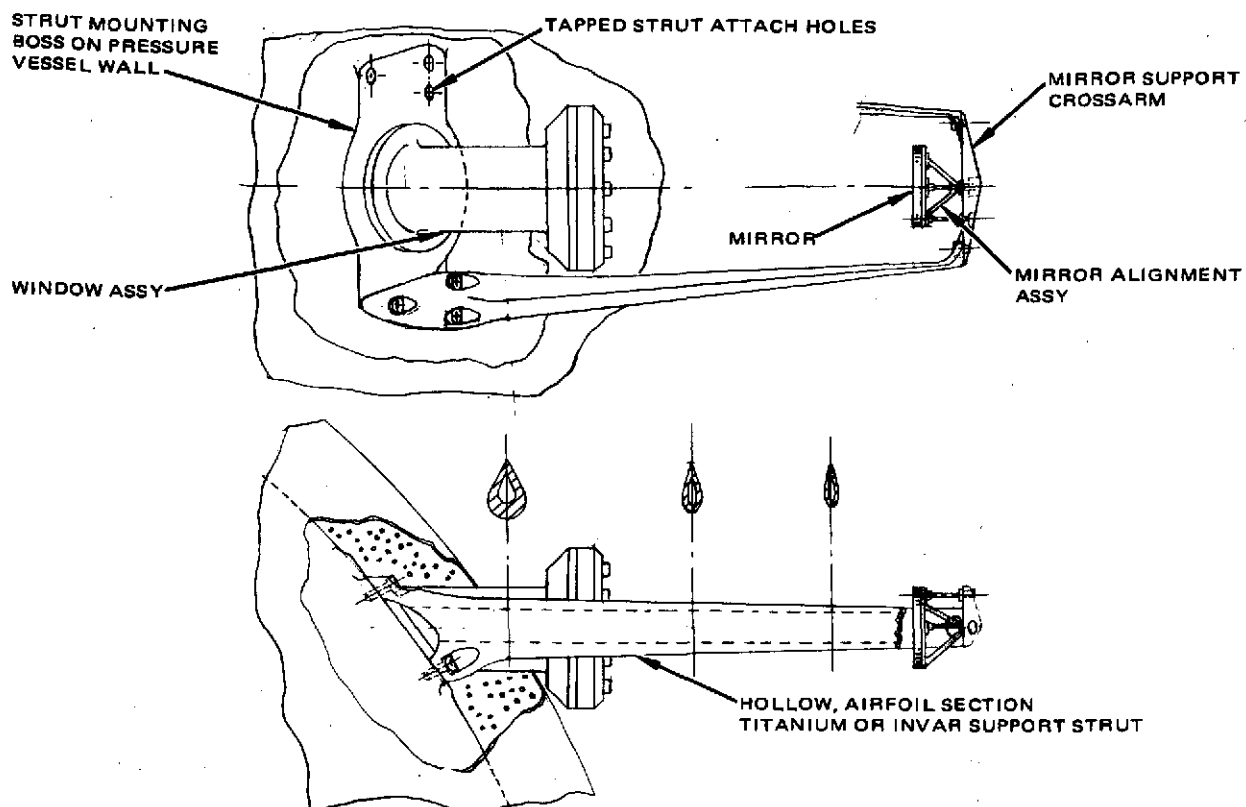
Pressure gauges

Characteristics of these instruments are given in Table 3-27.

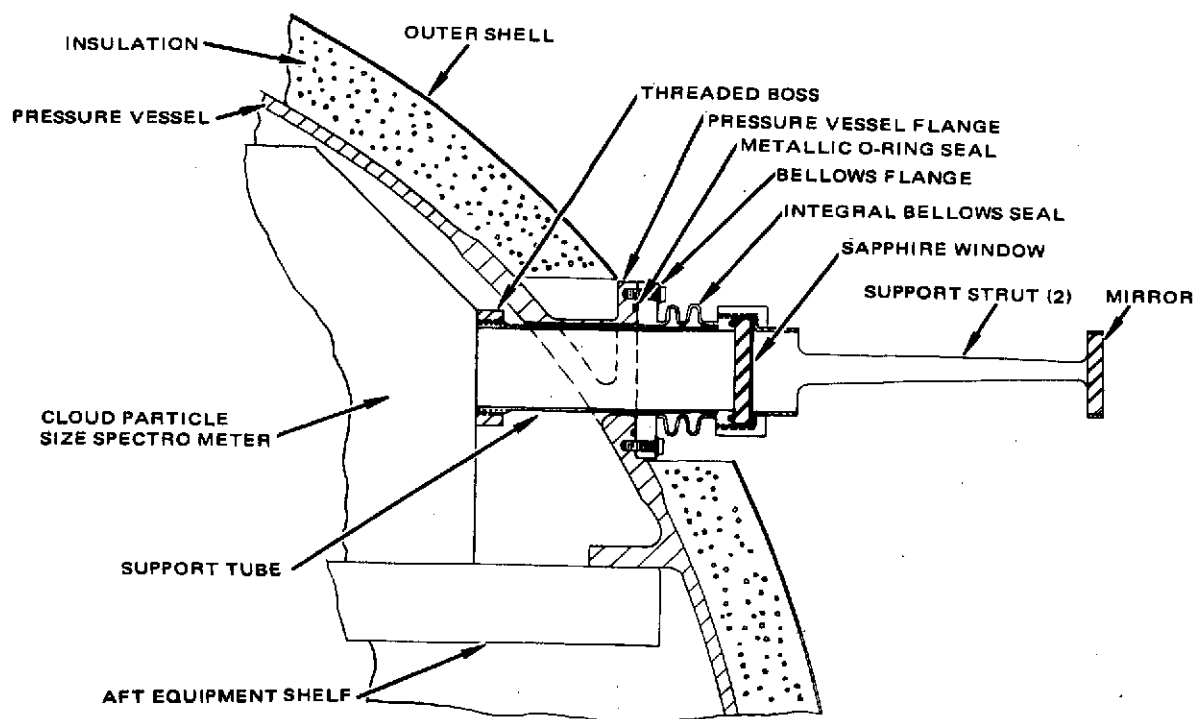
The principal reason for this study was the potential for mass reduction. That is, the mass of the pressure vessel shell is directly proportional to the volume it encloses; any reduction in the volume requirements implies a reduction in structural mass.



INSIDE MOUNTED INLET ASSY - BELLOWS SEAL  
FIGURE 3-13. MASS SPECTROMETER INLET SYSTEM



"BRIDGE" TYPE SUPPORT STRUCTURE



MIRROR SUPPORT INTEGRAL WITH EXPERIMENT

FIGURE 3-14. CLOUD PARTICLE SIZE SPECTROMETER MIRROR SUPPORT STRUCTURE CANDIDATE CONFIGURATIONS

FOLDOUT FRAME

FOLDOUT FRAME

30163-139 (U)

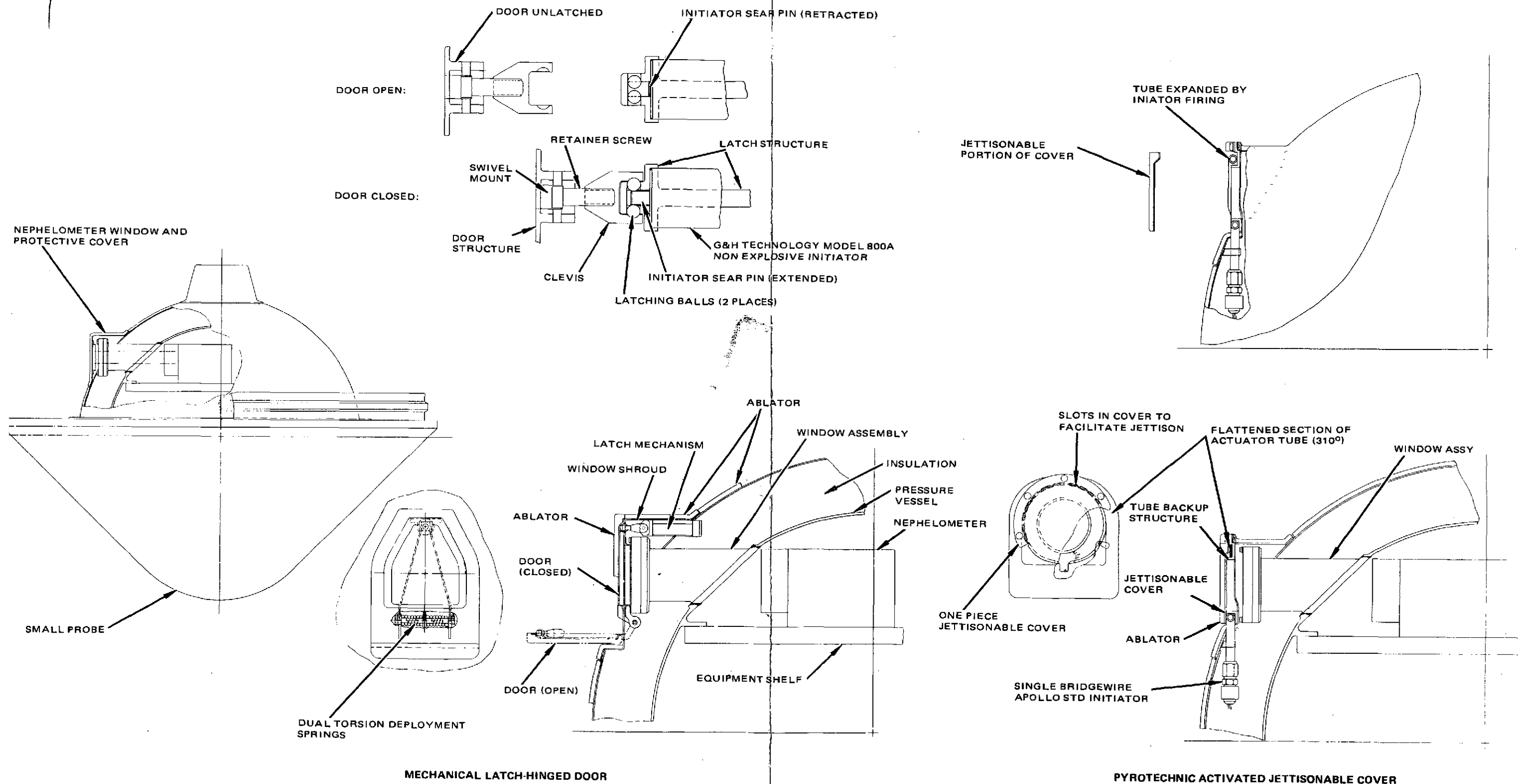


FIGURE 3-15. SMALL PROBE NEPHELOMETER WINDOW PROTECTIVE COVER CANDIDATE CONFIGURATIONS

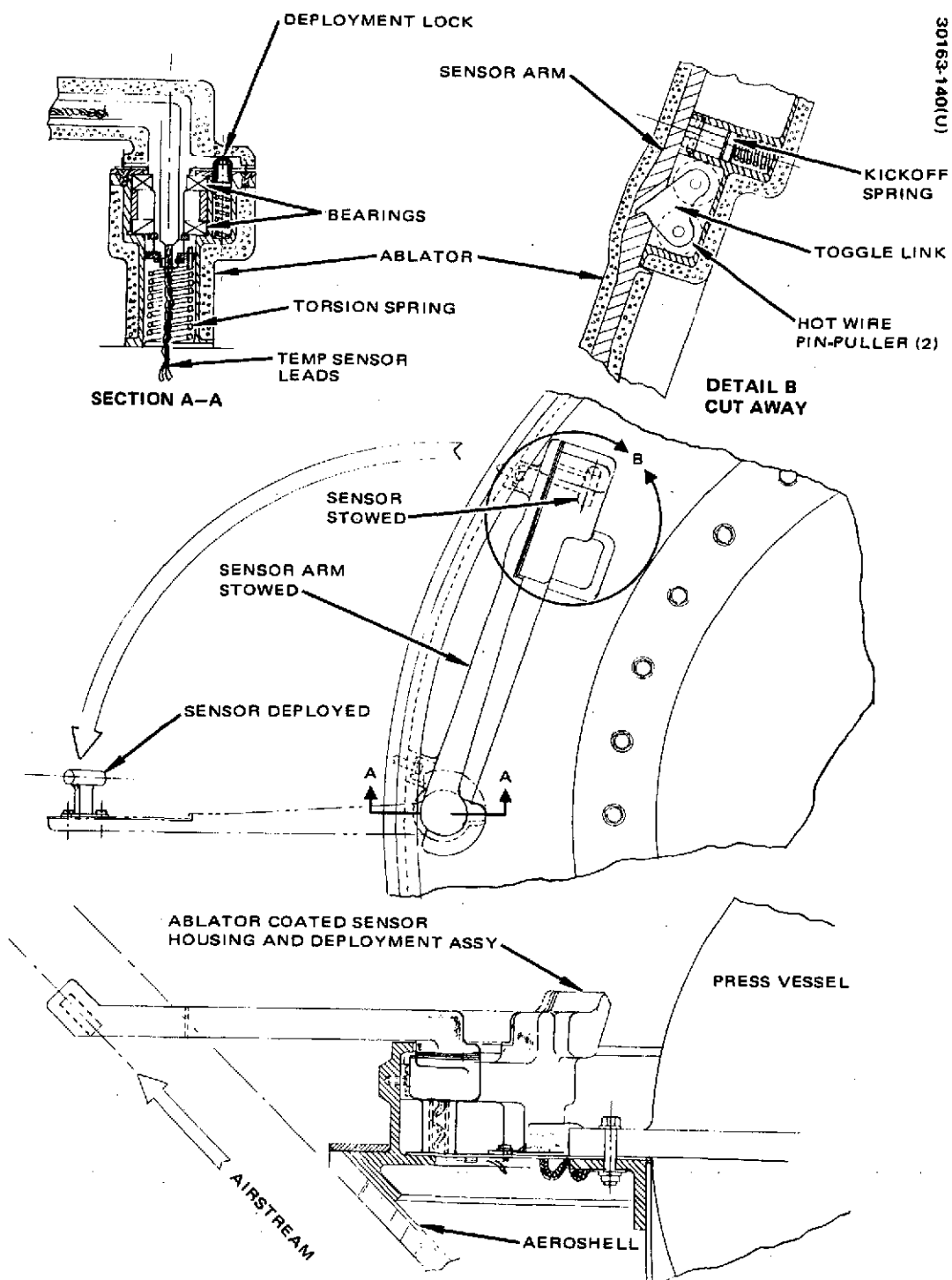


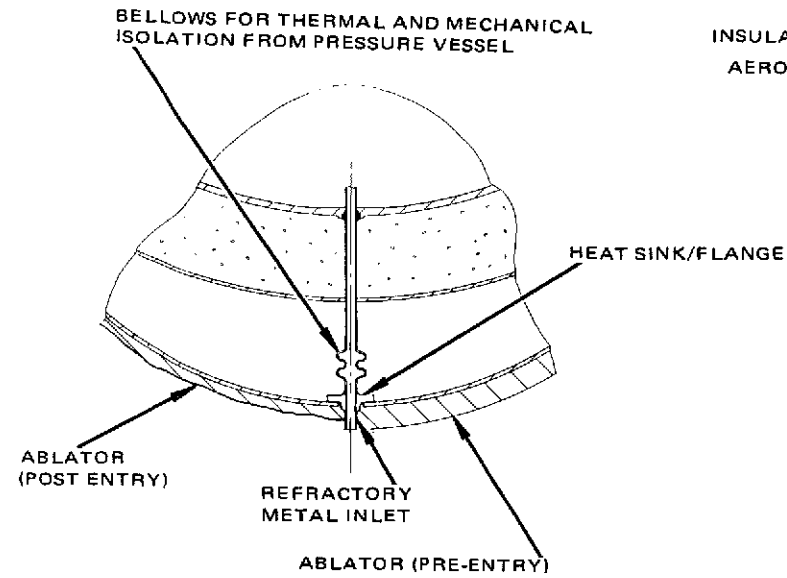
FIGURE 3-16. SWING ARM DEPLOYABLE TEMPERATURE SENSOR

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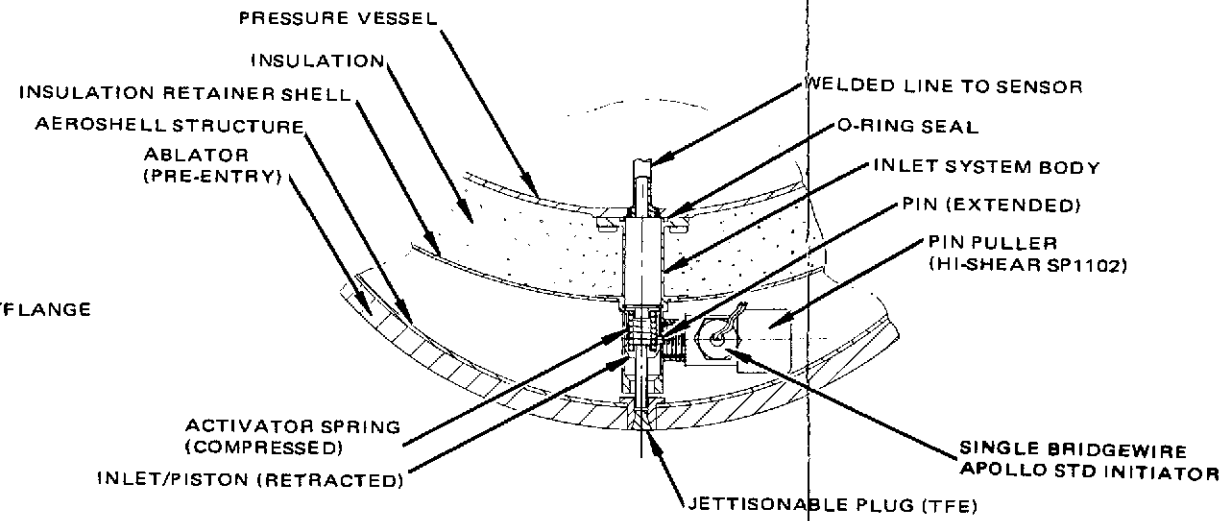
TABLE 3-27. SUMMARY CHART FOR EXTERNALLY MOUNTED INSTRUMENTS

Instrument	Mass		Volume		Temperature				No. of Wires
	kg	lb	cm <sup>3</sup>	in. <sup>3</sup>	Operating		Nonoperating		
					°C	°F	°C	°F	
Large Probe									
Pressure gauge, high altitude	0.225	(0.5)	66	(4.0)	-54 to +204	-65 to +400	-62 to +204	-80 to +400	4
Aureole extinction detector	1.8	(4.0)	1966	(120.0)	-54 to +57	-65 to +135	-54 to +74	-65 to +165	18
Hygrometer									
Sensor	0.09	(0.2)	8.2	(0.5)	-54 to +57	-65 to +135	-54 to +74	-65 to +165	2
Electronics	0.37	(0.8)	320	(19.5)	-54 to +57	-65 to +135	-54 to +74	-65 to +165	5
Small Probe									
Pressure gauge, high altitude	0.2	(0.45)	66	(4.0)	-54 to +204	-65 to +400	-62 to +204	-80 to +400	4

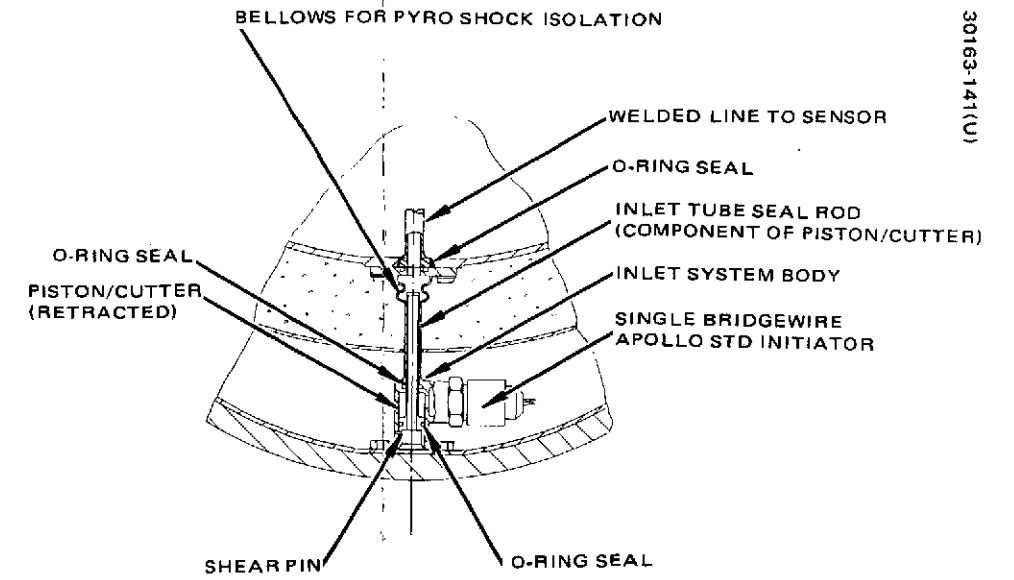
FOLDOUT FRAME



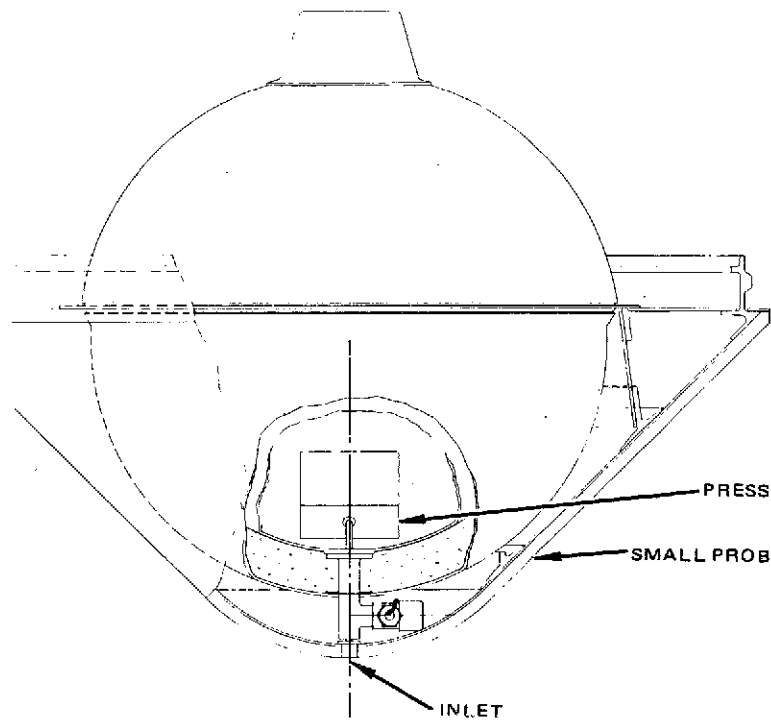
SURVIVABLE PROBE INLET SYSTEM



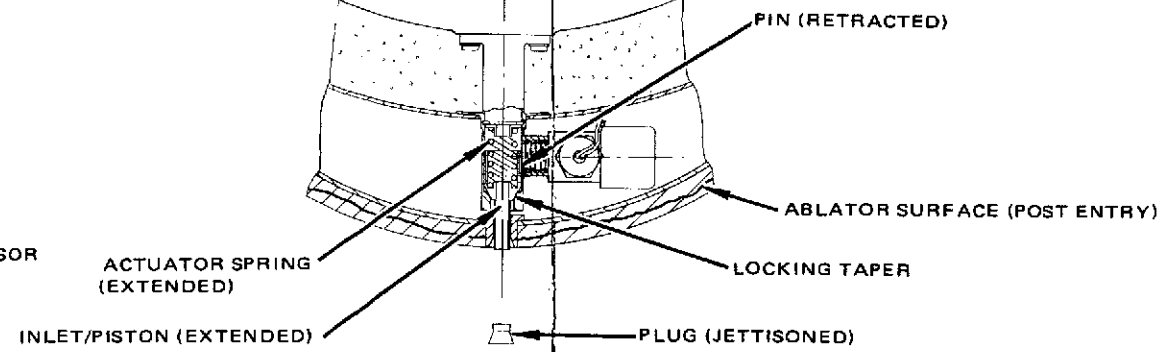
JETTISONABLE PLUG INLET SYSTEM: INLET RETRACTED



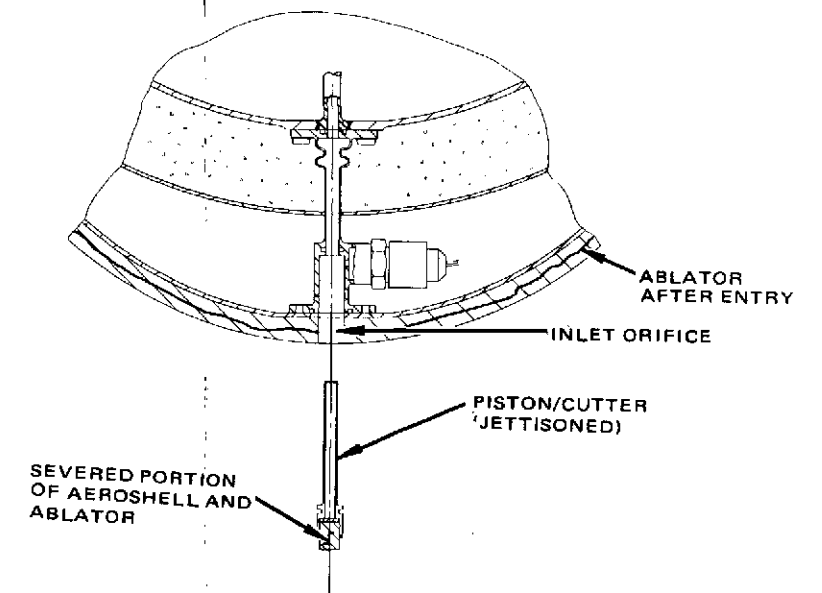
PYROTECHNIC CUTTER INLET SYSTEM: BEFORE ACTIVATION



PRESSURE SENSOR INLET SYSTEM LOCATION



JETTISONABLE PLUG INLET SYSTEM: INLET DEPLOYED



PYROTECHNIC CUTTER INLET SYSTEM: INLET DEPLOYED

FIGURE 3-17. SMALL PROBE STAGNATION POINT PRESSURE SENSOR INLET SYSTEM CANDIDATE CONFIGURATIONS



The ratio of internal volume to the total volume of all boxes contained in the pressure vessel (packing factor) is about 2.25 for both large and small probes. Thus, a 0.45 kg (1 lb) saving in large probe pressure vessel mass requires a 737 cm<sup>3</sup> (45 in<sup>3</sup>) decrease in package volume. The comparable figure for the small probe is about 1050 cm<sup>3</sup>/kg (29 in<sup>3</sup>/lb).

Table 3-27 indicates a total volume of 2294 cm<sup>3</sup> (140 in<sup>3</sup>) involved in the hygrometer and aureole extinction detector. Based on the sensitivity factors of the preceding paragraph, removing these instruments from the large probe pressure vessel could result in a maximum structural and insulation mass reduction of 1.4 kg (3.1 lb).

Removal of high altitude pressure sensors from within either large or small probe pressure vessels appears to have an insignificant effect on system mass.

External placement of the hygrometer, aureole extinction detector, and pressure sensors involves these considerations:

- 1) Mounting structure
- 2) Insulation
- 3) Harness penetration
- 4) Vehicle balance
- 5) Aerodynamic symmetry
- 6) Harness detach (if separable with parachute)

All of these items are over and above the normal integration requirements of the instrument. Thus, the mass penalties they imply are to be subtracted from the structural and insulation mass decreases accomplished by decreasing the pressure vessel diameter. A first assessment results in the following conclusions:

#### Mounting Structure

Brackets which mount to the pressure vessel shell and take the entry deceleration loads as cantilevered structures represent insulation penetrations (short circuits) whose main effect is probably in complexity of insulation installation.

#### Insulation

Instrument operating temperature limits are -53°C to +57°C (-65°F to +135°F) while the atmosphere temperature in the altitude range of interest varies from about -40°C to 110°C (-40°F to +230°F). Conclusion - no insulation is required.

#### Harness Penetration

An additional insulation and pressure vessel penetration is required to support a 25-wire bundle. Estimated mass is 45g (0.1 lb).

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TABLE 3-28. LARGE PROBE INSTRUMENT ALIGNMENT SUMMARY

Instrument	Altitude, km		External Probe	Port	Window	El/Az FOV, deg	Alignment to Spin Axis deg	Special Requirements
	On	Off						
Temperature	70	0	Yes	No	No	-	-	None
Pressure	70	0	No	Yes	No	-	-	Port at stagnation point
Accelerometer	130	*	No	No	No	-	0.017	At c. g. of probe
Neutral mass spectrometer	70	0	No	Yes	No	-	-	-
Cloud particle analyzer	70	0	Yes	No	Yes	-	-	1) Mirror 1 mr alignment required 2) In large, smooth mass flow region
Solar flux radiometer	70	0	No	No	Yes	$\pm 45/30$	-	Knowledge of local vertical to $\pm 2$ deg
Planetary flux radiometer	70	0	No	No	Yes	5	0.5	-
Aureole extinction	96**	46**	No	No	Yes	15/0.5	-	Must see the sun
Transponder	***	0	No	No	No	-	-	-
Nephelometer	70	0	No	No	Yes	< 0.5	-	None
Shock layer radiometer	130	70	No	No	Yes	$\sim 20$	-	-
Hygrometer	70	48	Yes	No	No	-	-	None

\* Accelerometer will remain on after landing to act as seismometer

\*\* On at 1/10 mbar, off at 2000 mbar

\*\*\* On 15 minutes prior to entry

### Vehicle Balance

Vehicle aerodynamic performance requires that the center of gravity and spin axis be aligned. If the pressure vessel diameter is reduced to take maximum advantage of the volume decrease, internal units cannot be shifted to balance the externally-mounted units. The hygrometer and pressure sensor together have a mass of 0.7 kg (1.5 lb), while the aureole detector is 1.8 kg (4.0 lb), requiring ballast for overall c. g. alignment. Estimated mass penalty is 1.1 kg (2.5 lb).

### Aerodynamic Symmetry

Spin tunnel tests of several sample protuberances indicate that there is no significant penalty from externally mounted packages of this size. Hence there is no mass penalty.

### Harness Detach/Chute Mounting

If the instruments are mounted to a structure which is removed when the parachute is jettisoned, a cable-cutter is required to sever the harness. Estimated mass penalty is 0.2 kg (0.5 lb). (This mode potentially saves ballast mass, but requires that the parachute be retained to lower altitudes than currently planned - a potential mass penalty).

These assessments may be summarized rather succinctly: external mounting of the hygrometer, aureole detector, and high altitude pressure sensor results in a significant increase in system complexity and virtually no mass saving.

The experiments selected for this study were based on system design considerations appropriate to the Thor/Delta baseline. Mass, volume, complexity, cost and existing technology were all factors for the Delta baseline.

The larger payload capabilities of the Atlas/Centaur launch vehicle do not change the conclusion reached in this study.

### External Sensors Alignment/Stability Study (EX11)

This study task examined the alignment and stability requirements of all probe experiments, not just those that protrude externally from the pressure vessel as originally defined. Probe bus experiments were also considered.

The results of this study are summarized in Table 3-28 for the large probe, Table 3-29 for the small probe and Table 3-30 for the probe bus.

TABLE 3-29. SMALL PROBE INSTRUMENT ALIGNMENT SUMMARY

Instrument	Altitude, km		External Probe	Port	Window	FOV, deg	Alignment to Spin Axis deg	Special Requirements
	On	Off						
Temperature	70	0	Yes	No	No	--	--	None
Pressure	70	0	No	Yes	No	--	--	Port at stagnation point
Nephelometer	70	0	No	No	Yes	15	--	None
Accelerometer	80	0	No	No	No	--	0.017	At c. g.
Magnetometer	70	0	No	No	No	--	$\pm 2$	Magnetic cleanliness
Stable oscillator	*	0	No	No	No	--	--	--

\* 15 minutes prior to entry.

TABLE 3-30. PROBE BUS INSTRUMENT ALIGNMENT SUMMARY

Instrument	Altitude, km		External Probe	Port	Window	FOV, deg	Alignment to Spin Axis, deg	Special Requirements
	On	Off						
Neutral mass spectrometer	2000	*	No	Yes	No	--	--	Inlet port parallel to velocity vector
Ion mass spectrometer	2000	*	No	Yes	No	--	--	Inlet port parallel to velocity vector
Electron temperature	2000	*	Yes	No	No	--	--	--
UV fluorescence	2000	*	Yes	No	Yes	--	$10 \pm 1$	$\pm 0.05$ deg grating alignment
Magnetometer	**	*	Yes	No	No	--	$\pm 1$	

\* On till burn up

\*\* On continuously

There are only five instruments which have a significant potential alignment problem: the accelerometer, cloud particle analyzer and the planetary flux instruments on the large probe, and the accelerometer and magnetometer on the small probe.

All instruments are discussed briefly below:

#### Large Probe

- 1) Temperature Gauges - Two temperature gauges were to be located in an area of high flow. The precise location of these probes is not critical; however, the sensor should be well insulated from the rest of the probe and be outside the vehicle boundary layer. The Science Steering Group suggest that radiative shielding may be required. For symmetry, the two temperature gauges should be on opposite sides of the probe but this alignment is not critical. The new Atlas/Centaur payload only requires a single probe.
- 2) Pressure Gauges - Two pressure ports were to be located as near to the stagnation point as possible and 180 deg apart. There are no alignment or stability problems; however, some care should be taken so that ports do not become clogged should there be particulate matter in the Venusian atmosphere. The new Atlas/Centaur payload only requires a single port.
- 3) Accelerometers - The accelerometers should be located at the c.g. of the probe and should be aligned within one minute of arc (0.017 deg) to the probe's spin axis.
- 4) Neutral Mass Spectrometer - No external alignment or stability problems exist for this instrument.
- 5) Cloud Particle Size Analyzer - The mirror mounted on the bridge should be aligned to within one milliradian of the source beam axis during the parachute and free-fall part of the descent.
- 6) Solar Flux - There are no alignment or stability problems. This instrument requires sun-side descent.
- 7) Planetary Flux - This instrument looks parallel to the spin axis. Its field of view is 5 deg (full angle) so that its alignment with the spin axis should be on the order of 0.5 deg.
- 8) Aureole Extinction Detector - There are no alignment problems for this sensor. This sensor requires a sun-side landing and should point within 7 deg of the sun.
- 9) Transponder - This experiment uses the communication system of the spacecraft. For good data transmission, the spin vector (antenna boresight direction) and the local vertical should be within 10 deg.

10) Nephelometer - In the November experiment data book, this instrument was described as having a separate light source and detector (with about a  $45^\circ$  angular separation), and hence would have an alignment problem. However in January it was learned from NASA ARC that the instrument will be of the "LIDAR" type (a laser radar, with a pulsed signal leaving the source and a detector looking for directly backscattered light). The detector and source are coincident in this case, hence no alignment problems exist.

11) Shock Layer Radiometer - This instrument is externally mounted in the heat shield and looks at the shock layer in front of the heat shield. Each sensor is fairly broad ( $\sim 20$  deg) and therefore no alignment problems are expected.

12) Hygrometer - The hygrometer must be located beyond the boundary layer of the pressure vessel, but there are no alignment problems.

#### Small Probe

1) Temperature Probe - The temperature probe should extend beyond the boundary layer and be parallel to flow in an area of maximum mass flow.

2) Pressure Gauge - The pressure port should be at the stagnation point. Otherwise, no alignment problems exist.

3) Nephelometer - No problems are anticipated. Location of the nephelometer should be such as to minimize the line-of-sight distance through the boundary layer and/or wake.

4) Accelerometer - The accelerometer should be located at the c.g. and be aligned to the spin axis within 1 arcmin.

5) Magnetometer - The magnetometer should be aligned within  $\pm 2$  deg of the spin axis.

6) Stable Oscillator - This is part of the telecommunications system and has no additional alignment requirements.

#### Probe Bus

1) Neutral Mass Spectrometer - The inlet of the neutral mass spectrometer should be mounted parallel to the velocity vector of the spacecraft.

2) Ion Mass Spectrometer - The inlet port of the ion mass spectrometer should be parallel to the velocity vector of the spacecraft.

3) Electron Temperature Probe - The probe should be mounted perpendicular to the velocity vector and be deployed after all 1 g magnitude or greater maneuvers are completed.

4) UV Fluorescence - The experimenter would like the spin axis to be displaced from the velocity vector by 10 deg and the boom on which the grating is mounted to be displaced 10 deg from the perpendicular (to spin axis) position. The grating should be aligned within 0.05 deg to the source and detector. For this experiment, it is important to know the spin rate to within 2 percent.

5) Magnetometer - The magnetometer should be mounted on a boom to reduce spacecraft related magnetic interference. (See trade study on magnetometers - EX 15). The sensor axis should be parallel to the bus spin axis within 1 deg.

### Implications

It is apparent that there are two problem categories: 1) alignment of the instruments with the vehicle, and 2) internal alignment within the instruments. Consider the latter first.

Internal Alignments. The cloud particle analyzer employs a mirror which must be extended into the "airstream" some 15 to 20 cm (6 to 8 in.) outboard of the instrument window and optics. The one milliradian alignment requirement refers to the angle between the mirror normal and the optics boresight. Two instrument mounting approaches have been devised and are illustrated in Figure 3-14. The first is a technique whereby the mirror support structure is integral with the instrument and contains the pressure-seal window. In this arrangement, the mirror can be aligned in as controlled an environment as desired prior to instrument installation in the pressure vessel. A bellows seal to the pressure vessel shell compensates for instrument/shelf/shell alignment uncertainties. The mirror alignment can be performed to the 1 mr required, and the only subsequent source of misalignment would be environmental effects, pressure and temperature.

The second mirror mount uses a bridge attached directly to the pressure vessel shell. The rest of the instrument is wholly contained within the pressure vessel. Because of assembly tolerances, the mirror must be aligned after instrument installation, indeed, after final assembly of the pressure vessel. Inherently, this initial alignment probably cannot be made as accurately as with the integral mount. Furthermore, it has an additional source of misalignment, in that the pressure vessel shape may change slightly during descent.

The effects of pressure, more specifically dynamic pressure, on the mirror mount are negligibly small. During free fall, dynamic pressure is about  $2155 \text{ N/m}^2$  (45 lbs/ft<sup>2</sup>). This leads to mirror deflections of the order of 20 arcsec, depending on the detailed design of the mount.

TABLE 3-31. EX15 MAGNETOMETER TRADEOFF STUDY RESULTS

	Type	Advantages	Disadvantages
Probe bus and orbiter	1.1 m (42 in.) boom (Thor/Delta baseline)	Short boom has less impact on spacecraft control Low boom cost Lower mass -2.1 kg (4.7 lb)	High magnetic control costs (~\$ 2M) High background ~8 gamma magnetized ~1 gamma demagnetized
	4.6 m (15 ft) boom (Atlas/Centaur baseline)	Low magnetic background Low magnetic control costs (magnetic tests and small probe magnetic control ~\$ 500K)	Long boom impacts spacecraft control High boom mass -6.8 kg (15 lb) High boom costs
Small probe	Sensor within pressure vessel (baseline)	Least impact on probe dynamics Low mass	High magnetic background ~600 gamma magnetized ~85 gamma demagnetized
	Sensor external to pressure vessel	Lower magnetic background	Impacts probe dynamics Higher mass Requires thermal insulation Possible interference with antenna pattern



Thermal distortion of the mount could be caused by temperature differences between the two arms and/or by temperature gradients in the arms. The temperature difference between arms which produces a 1 mr deg mirror misalignment is coincidentally approximately the same as the gradient within the arms which produces the same amount of distortion - about  $5.5^{\circ}\text{C}$  ( $10^{\circ}\text{F}$ ). It is difficult to conceive how differences this high could occur; temperature variations in the mirror mount structure will probably be of the order of a deg.

Finally the mount which is attached to the pressure vessel shell could rotate because of shell growth. That is, temperature gradients around the shell (caused primarily by the shelf mounting rings) will cause the shell to seek a stress-free condition which is slightly nonspherical. A very conservative analysis was made of this condition, using the worst gradient indicated for any insulation thickness, which was  $167^{\circ}\text{C}$  ( $300^{\circ}\text{F}$ ). The analysis indicated a maximum mirror mount rotation of about 5 arcmin, which is significant.

It is therefore concluded that for the cloud particle analyzer mirror to be within alignment tolerances, the integral mount should be employed.

External Alignment. The other class of problem is concerned with aligning instruments to the vehicle spin axis. Large and small probe accelerometers appear to require tolerances of 1 arcmin. This sort of accuracy (and better) is achieved routinely in mounting sun and star sensors to spacecraft and there is no reason to expect that it could not be achieved here with respect to some vehicle coordinate system. However, it appears unlikely that vehicle aerodynamics will permit knowledge of the spin axis position to this accuracy. The problem is complicated by ablation process uncertainties in the entry phase and by the very small static stability margin of the pressure vessel during free fall.

It is therefore concluded that accelerometer alignment with the spin axis cannot be achieved within the accuracy specified, but that alignment with respect to a known vehicle axis is readily achievable.

Planetary flux sensor alignment within one-half deg of the pressure vessel spin axis can probably be achieved. Magnetometer alignment within 2 deg of the small probe spin axis is also readily attained.

#### Magnetometer Studies (EX15)

The purpose of this task was to determine the requirements and locations for the magnetometers on the small probes, probe bus and orbiter. Table 3-31 summarizes the results of the tradeoff study, showing the advantages and disadvantages of various approaches to magnetometer location in the probe bus and in the small probe. The cost for a tight magnetic control program for the small probe is grossly estimated to be 2 percent of the total cost of the probes.

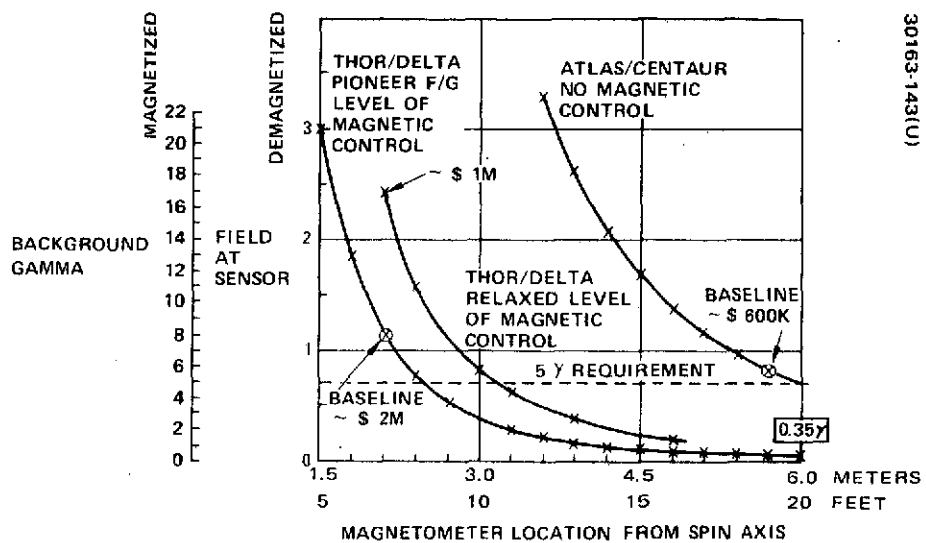


FIGURE 3-18. PROBE BUS AND ORBITER BACKGROUND VERSUS BOOM LENGTH

In the probe bus, the various boom lengths and degrees of magnetic control assume a requirement of 5 gamma background after the spacecraft has been magnetized in a 25 G field. If the 5 gamma background requirement is for a demagnetized spacecraft, a 1.1m (42 in.) boom would suffice. Figure 3-18 shows the background as a function of boom length for various levels of magnetic control for both the Thor/Delta and Atlas/Centaur launch vehicles. Because of severe mass limitations, a 1.1m (42 in.) boom was selected as a baseline for the Thor/Delta. However, for the Atlas/Centaur, where mass is not a problem, a 4.6m (15 ft) boom was chosen because of the low magnetic control costs.

In the small probes the magnetometer experiment will return useful data on the magnetic field of Venus if the magnetic field background of the probe subsystems is limited to 100 gamma, (Reference 2-5). Calculations show that the 100 gamma background cannot be achieved when the probe is in a magnetized condition, that is, after the small probe has been subjected to a 25 G magnetizing field. However, information obtained from NASA/Ames (on 11 January 1973) implies that the 100 gamma requirement is for the small probe in a demagnetized condition. The 100 gamma requirement could conceivably be met if a 6 or 7 to 1 reduction from the magnetized condition is assumed for the demagnetized condition.

The small probe magnetic background at the magnetometer has been calculated to be just under 600 gamma on any one of the three axis sensors, after the probe has been magnetized in a 25 G three-axis environment.

Magnetic specifications typically require a demagnetized field of between 1/6th to 1/8th of the magnetized field. An example of this would be Pioneer F/G requiring 1/4 gamma when magnetized and 0.04 gamma when demagnetized, a ratio of approximately 6:1. The same would be expected on the small probe, which would result in a demagnetized field of between 72 gamma and 96 gamma.

The specification of the stray or operating magnetic field requirement, which is the third condition to be met in a magnetic control program, is the most difficult to deal with. This is a field level requirement that must not be exceeded at the sensor while the probe is being operated throughout all of its flight operating modes. It involves the magnetic fields generated by current loops within the spacecraft harness, the power feeds and returns and any returns through the structure, and current loops due to component and circuit layouts in assemblies. It involves then both stray dc fields and ac fields of frequencies up to the bandpass limit of the magnetometer. This is usually 0 to 25 Hz for fluxgates but is expected to be much lower for the magnetometer on the probe.

At the early program stages, other than following good magnetic control design practices, little can be done as circuits and layouts are not in being. The orientation of an assembly or the amount of current and its direction of flow is unknown; therefore, it is not possible to calculate whether a particular current loop adds to or subtracts from some other loop.

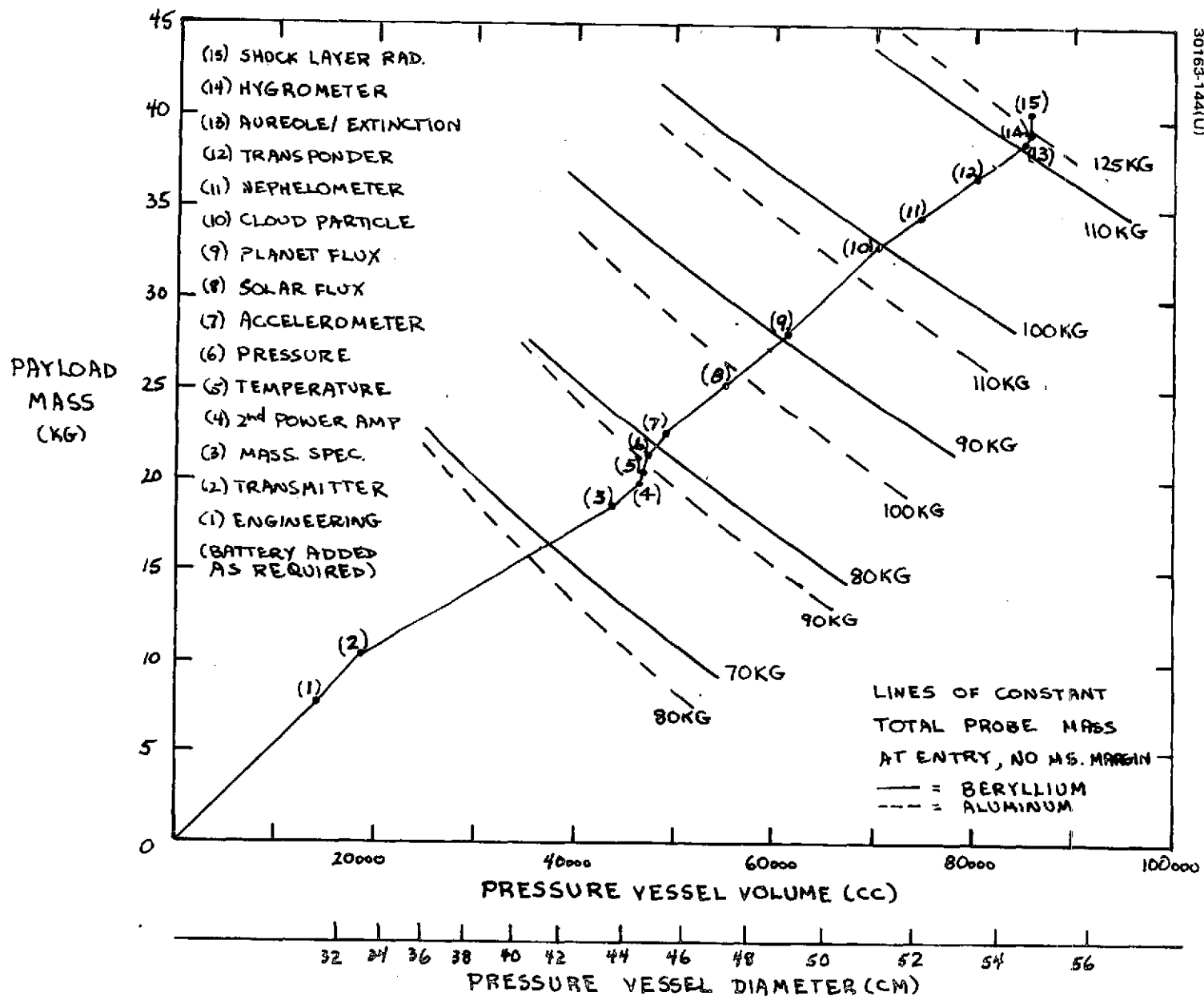


FIGURE 3-19. LARGE PROBE PAYLOAD MASS AND VOLUME REQUIREMENTS

Unlike the magnetized condition where all soft materials line up when magnetized, fields generated by current loops do not. Problems are expected with stray fields with the small probe. The extreme packing density and closeness of operating circuits to the sensor could provide a field from some operating circuit that is outside the specification requirement.

In the Atlas/Centaur payload received 18 April 1973, the magnetometers have been deleted from both the small probe and the probe bus nominal payloads, although still listed as another candidate instrument for the small probe.

### Payload Tradeoff Analysis (EX1)

The objective of this task was to study the integration requirements of the other candidate instruments. For the Thor/Delta, however, the payload was so severely mass limited that augmentation of the nominal payload did not seem warranted initially, and work on this task was delayed.

A new study task was defined, MS-24, Reduced Payload Analysis, to study the total spacecraft mass reduction achieved if the probe science payload were reduced, Figure 3-19 shows payload mass and volume versus total large probe mass, as the science payload is incrementally reduced. Figure 3-20 shows the same for the small probe. This parametric analysis allows the major impact of each instrument on the probe to be evaluated. (The existence of a separate study task, PB 35, Payload Growth Study, to determine the effect on the large probe design of adding other candidate instruments should also be noted here).

Atlas/Centaur is not mass-limited and further work on EX1 was initiated following receipt of the Atlas/Centaur payload on 18 April, accompanied by a new set of other candidate instruments, which are shown in Table 3-32, with upper limits for mass, volume, and power. Half of these had been nominal instruments on earlier payloads.

The various impacts to the probes and probe bus if any one of the candidate experiments were to be included with the respective nominal payloads have been examined and are discussed here.

The conclusions reached are that the magnetometer instrument of the small probe and probe bus and the ATR instrument of the large probe, would have the major impact on the present designs, as summarized in Table 3-33.

### Large Probe

X-ray Fluorescence. The X-ray fluorescence experiment consists of a separate electronic unit and a sensor. The sensor, to be mounted external of the pressure vessel, comprises two gas filled proportional counters along with two radioactive devices. Its purpose is to measure radiation induced X-ray fluorescence from the dust or aerosols in the airstream. The sensor

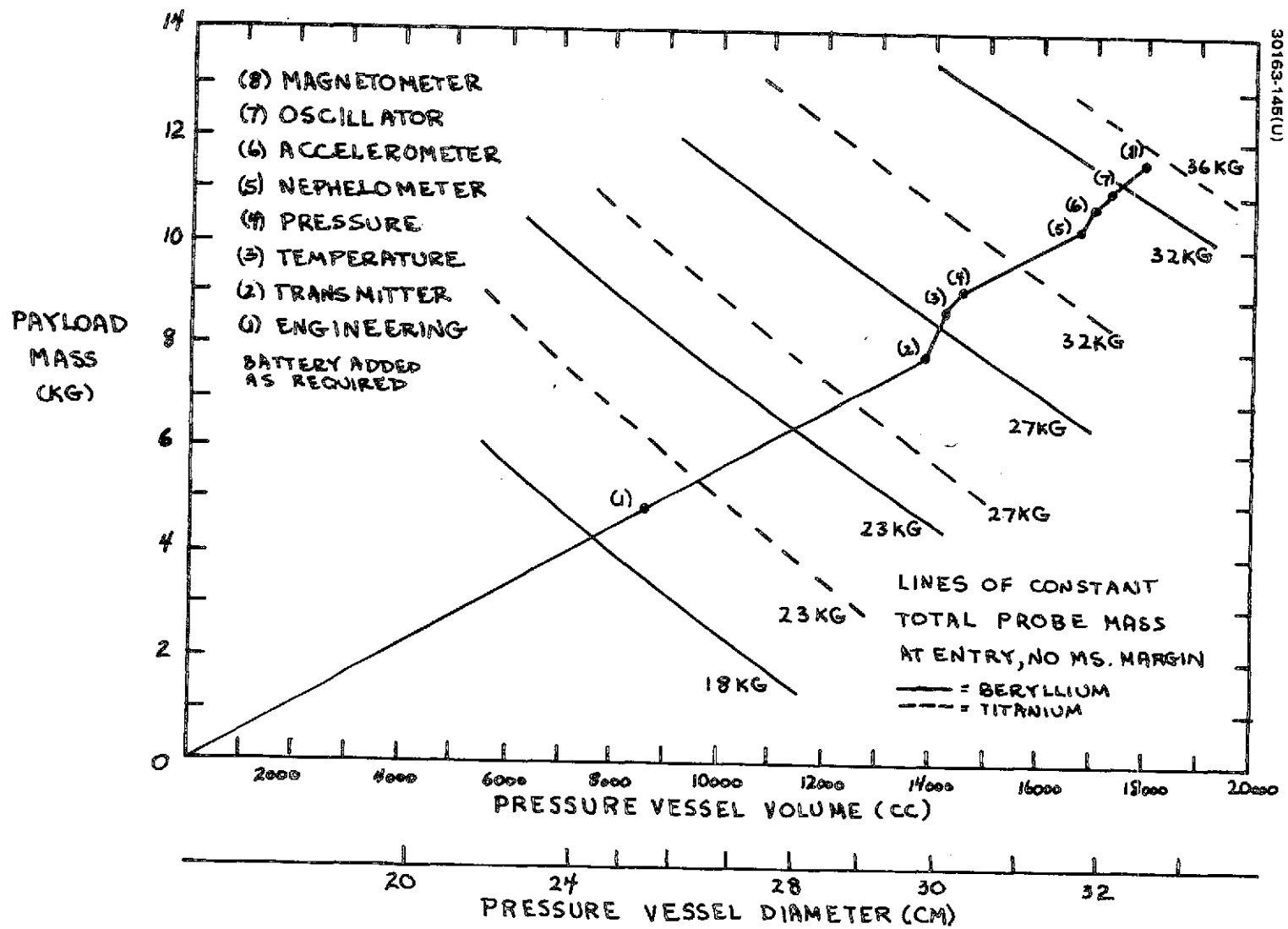


FIGURE 3-20. SMALL PROBE PAYLOAD MASS AND VOLUME REQUIREMENTS

TABLE 3-32. OTHER CANDIDATE INSTRUMENTS FOR MULTIPROBE MISSION

Instrument	Mass kg (lbs)	Volume cm <sup>3</sup> (in <sup>3</sup> )	Power W	Data Rate bps
<u>Large Probe</u>				
X-ray fluorescence	2.8 (6.3 )	3392 (207 )	2.4	9
ATR spectrometer	2.8 (6.3 )	1725 (106 )	6.0	36
Aureole detector	2.3 (5.2 )	2829 (173 )	3.0	16
Shock layer radiometer	1.3 (2.8 )	499 ( 31 )	1.2	NA store
<u>Small Probe</u>				
RF altimeter	0.52 (1.2 )	263 ( 16 )	5.5	1.0
Magnetometer	0.52 (1.2 )	227 (13.8)	1.2	1.7
<u>Probe Bus</u>				
Solar wind analyzer	1.56 (3.4 )	2415 (147 )	3.0	58 cruise and entry
Magnetometer	2.6 (5.75)	4515 (276 )	3.6	15 cruise 30 entry
<p>The above parameters include the tolerances:</p> <p>+15% mass +15% volume +20% power</p>				

TABLE 3-33. OTHER CANDIDATE INSTRUMENTS IMPACTING PRESENT DESIGN

Instrument	Requirement	Impact
<u>Large Probe</u>		
ATR	36 bps telemetry	RF subsystem redesign, mass increase, possible resizing of probe.
<u>Small Probe</u>		
Magnetometer	1000 gamma background 1 gamma stability 1200 bits storage	Magnetic control costs and data storage increase
<u>Probe Bus</u>		
Magnetometer	0.5 gamma background	Magnetic control costs

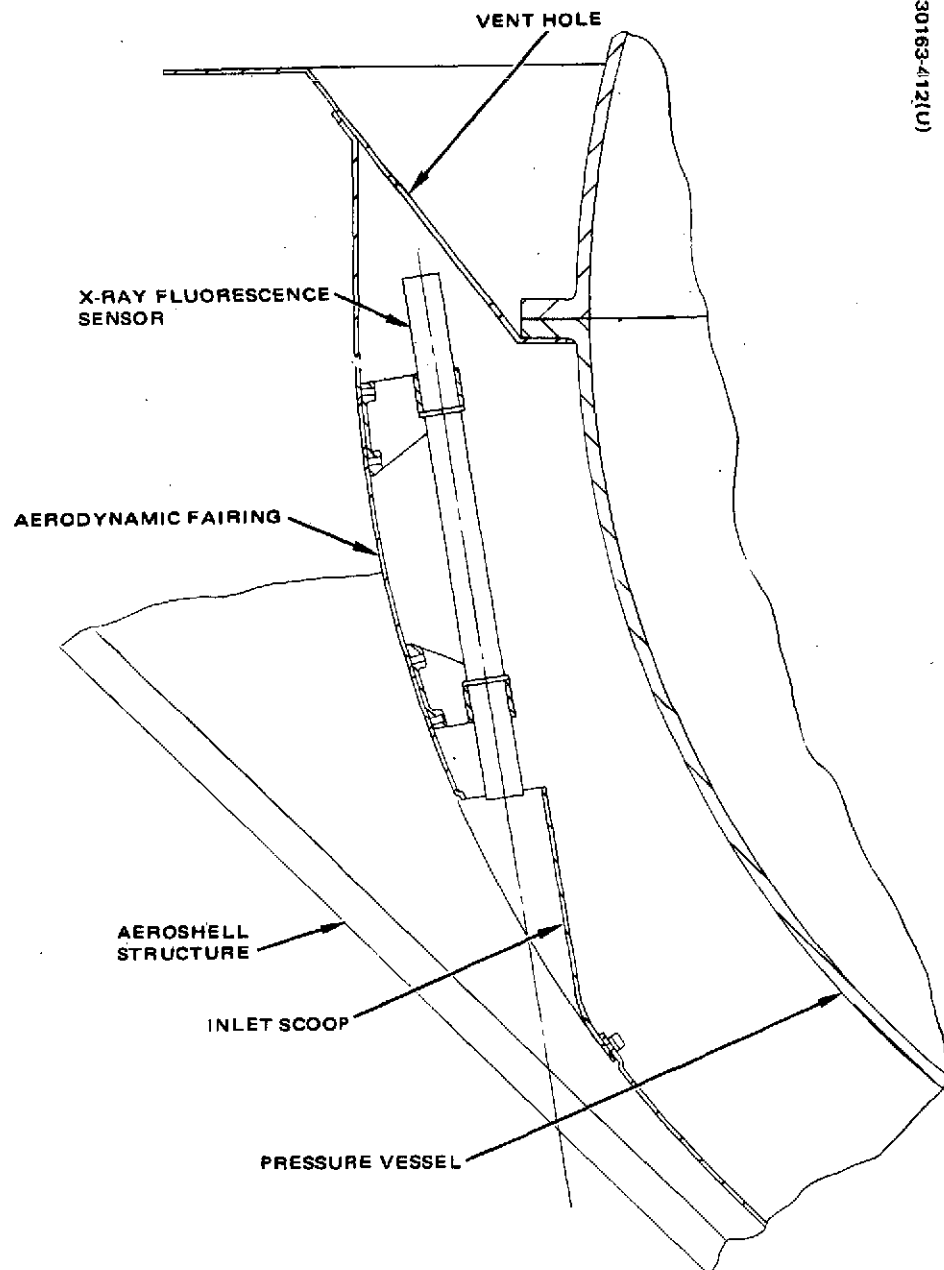


FIGURE 3-21. X-RAY FLUORESCENCE SENSOR



is a tube 12.7 cm (5 in.) in length and 2.5 cm (1 in.) diameter and is to be mounted with the larger dimension parallel to the descent axis. Operation is required from parachute deployment to the surface.

The requirement for an externally mounted sensor to be immersed in the main airstream was studied and the conclusion reached is that this would cause no large impact on the probe. A suitable mounting position would be on the inside of the aerodynamic cover with an inlet scoop in the cover to allow passage of the gases over the windows of the sensor. In this position it is not expected to have any large effect on the probe descent dynamics. A sketch of this mounting method is shown in Figure 3-21. The parameters given in Table 3-32 could also be accommodated in the existing design.

Attenuated Total Reflection (ATR) Spectrometer. The ATR spectrometer measures volatile heavy atoms by means of attenuated total reflection of infrared light. Material to be analyzed is condensed on a diamond window which is cleaned periodically by raising its temperature with a heating coil.

The instrument consists of an IR source, a chopper, scanning mirrors, a rotating wheel and drive motor. It requires a small (1 cm) opening in the pressure sphere for the mounting of the diamond window. No special orientation is required. Operation is from parachute deployment to the surface.

Study shows that the instrument could be located in the lower hemisphere with a small tube connecting the window mounted on the aerodynamic fairing through to the instrument in the pressure vessel. This same window along with the tube, would act as the pressure seal, alleviating the requirements for a second window in the pressure vessel.

The existing probe design can accommodate the ATR requirements along with the mass, volume and power requirements as shown in Table 3-32. The telemetry rate of 36 bps however, cannot be accommodated. The present downlink design is sized to the nominal payload telemetry requirement of 80 bps near the surface. An additional 36 bps (assuming this is the ATR requirement throughout the descent period) would require the following changes:

- 1) A fourth power amplifier module would be required.
- 2) The power amplifier module power and the experiment power would necessitate resizing the battery.
- 3) An additional thermal sink is required for the power amplifier.

The above additions result in the mass, volume, and power increases to the probe shown in Table 3-34 and while the study shows that these increases could be included in the present design of the large probe, the design becomes marginal. The addition of the ATR could possibly mean a larger pressure vessel size, and result in many other impacts throughout the entry module and probe bus.

TABLE 3-34. ATR SPECTROMETER IMPACTS ON LARGE PROBE

	Mass kg (lbs)	Volume cm <sup>3</sup> (in <sup>3</sup> )	Power W
ATR experiment	2.8 ( 6.3 )	1725 (106)	6.0
Power amplifier	0.54 ( 1.2 )	558 ( 34)	33.0
Battery increase	1.6 ( 3.54)	918 ( 56)	—
Power amplifier thermal sink	1.3 ( 3.0 )	—*	—
Totals	6.24 (14.04)	3201 (196)	39.0

\*No volume increase. Part of honeycomb platform changed to a solid.

Aureole Detector. The aureole detector measures the attenuation of the direct sun light which gives an indication of the extinction of the clouds and the aureole as bright haze around the sun.

Three separate units consisting of an electronic package and two sensors are required. The sensors are to be positioned in the upper hemisphere of the pressure vessel, one either side of the descent axis and viewing at an angle that will ensure passage through the sun during spin. Each sensor is housed in a 7.6 cm (3 in.) long tube which is internal of the sphere. Each requires a 0.32 cm (1/8 in.) pressure sealing window. Instrument operation is required from parachute deployment to the surface. Spin is required but the rate of spin is not critical.

The positioning of the sensors in the aft hemisphere and the small window requirements could be easily met and are not considered any impact on the probe design. The heating of the windows to prevent condensation could also be accommodated in the present design.

Shock Layer Radiometer. The shock layer radiometer measures the bulk species of the atmosphere from the radiation of the bow shock wave which precedes the heat shield during entry. The sensor consists of a number of light sensitive diodes and filters packaged into a small unit and mounted to view through the heat shield for observance of the shock wave. The electronics unit is separate and can be mounted either internal or external of the pressure sphere. The instrument operates only for that brief period during entry and requires data storage (~1000 bits) for playback after blackout. Jet-tison of the sensor and the electronics package (if external) will be made with the heat shield. The experiment will operate with or without spin.

This instrument had already been considered in the large probe design when it was a nominal experiment. At that time the heat shield was phenolic nylon and considered an ablation problem in and around that area of the quartz window of the shock layer sensor. The heat shield is now carbon phenolic which has a lower ablation rate and therefore eases the above problem. Should the instrument be flown however, further tests would be expected on the heat shield and the sensor.

The operation of this experiment during the blackout period requires a resizing of the existing data storage unit. This at present accommodates the storage of the accelerometer instrument along with some of the engineering measurements which result in a 2048 bit storage. The shock layer instrument requires a 1000 bit storage. Other than a small volume and mass increase this addition would not impact the large probe design.

### Small Probe

RF Altimeter. The RF altimeter consists of an electronics unit which houses the transmitter and receiver and a separate antenna system. The electronics unit will be mounted internal to the pressure vessel and the antennas external. Due to the extreme heating conditions during the entry phase, a deployment mechanism is required for the antennas. These consist of two whip antennas approximately 15 cm (6 in.) long and positioned 180 deg apart and at 90 deg to the spin axis. The frequency is 415 Mhz and operation is required from 50 km to the surface. The instrument will operate with or without spin.

A study of this requirement shows that two self deployed and squib activated whip antennas could be positioned on the aft step of the small probe. Thermal protection would be required when in the stowed position but the total system would be less than 0.114 kg (0.25 lb), and this along with the instrument mass, volume and telemetry parameters of Table 3-32 could be incorporated into the present probe design.

The power requirement of 5.5 W (this includes the 20 percent contingency) from 50 km to the surface would mean a resizing of the battery, resulting in a battery weight increase of 0.21 kg (0.47 lb) and a volume increase of 139 cm<sup>3</sup> (8.5 in<sup>3</sup>.)

Should this experiment be included along with the nominal payload, it is not expected to have a major impact on the probe.

Magnetometer. The magnetometer experiment measures the Venusian magnetic field. It consists of a single unit housing the two axis sensor and the electronics. One sensor axis is to be parallel to the probe spin axis and the other at 90 deg. Alignment of the sensor to the probe axis is 2 deg.

For the instrument to measure the planet field, the magnetic field of the probe must not exceed 1000 gamma and must be stable to within 1 gamma. It is also required that the probe spins (~5 rpm) and that the angular position of the probe be known in relation to some Venus coordinates.

Operation of the magnetometer is from 15 min prior to entry to the surface. Data storage is required (~1200 bits) during the blackout period.

The addition of the magnetometer experiment would have a large impact on the small probe design. While the mass, power, and volume would not appear to influence the present design, the fact that telemetry storage is required during the entry phase along with the requirement for magnetic control of the probe and subsystems to reduce the magnetic background level at the sensor, would result in a probe redesign.

The existing data storage is sized mainly for the accelerometer and is 512 bits. The magnetometer would require an additional 1200 bits.

Since the removal of this instrument from the nominal payload, changes have been made to the probe, many of which do not favor magnetic control for the reduction of the background magnetic field. Magnetic control is considered very necessary if the instrument is to measure the Venusian magnetic field.

In the rf communications subsystem, an rf isolator has been added to prevent damage to the power amplifier from the strong reflectance due to the ionizing layer at entry. The rf system is required to be on prior to entry and after for doppler tracking. For frequency stability reasons, it is also on during the blackout phase. The isolator exhibits a large magnetic field.

All probe units and the pressure vessel will, due to the absence of a magnetometer on the nominal payload, be designed without regard to magnetic control. The addition of a magnetometer would therefore result in a huge cost impact.

#### Probe Bus

Solar Wind Analyzer. The solar wind analyzer measures the energy, flux and direction of the solar wind charged particles. It is required to operate during cruise and throughout the entry period until bus destruction in the lower Venusian atmosphere.

The electronics and sensor are combined in one unit and will be positioned on the bus for external viewing by the sensor in the ecliptic plane. The FOV is approximately 150 by 10 deg. Bus spin is required (from 5 to 60 rpm) for scanning of the instrument throughout the 360 deg. During each scan, the instrument must see the sun.

The mass, volume and power requirements shown in Table 3-32 for this instrument could be accommodated on the existing design of the probe bus without causing any real impact. Some re-layout of the equipment platform would be necessary due to the large FOV (~120 by 10 deg), but this would be expected if any instrument were to be added to the nominal payload.

The probe bus rf downlink capability is, for most of the cruise phase, marginal in accommodating the additional 58 bps telemetry requirement of the

experiment. During this period the bi-cone antenna and 1 to 9 W power amplifier are in use.

During the larger part of the cruise phase, the total capability is 64 bps. Near the end and just prior to spacecraft orientation for probe release, the larger communication distance limits the bit rate to 48, part of which is required for spacecraft engineering data. There is no problem once the spacecraft has been positioned for probe release and final entry. The end-fire antenna is brought into use and both 9 W amplifiers to provide an ample bit-rate.

The requirement of 58 bps during cruise for this experiment appears extremely high. If it is a firm requirement, the second 9 W amplifier can be used. During the latter part of the cruise, the spacecraft-sun geometry does provide electrical power from the solar array for this operation.

A second and also minor problem would exist for any cruise experiment requirement on the probe bus. With the dual launch of the probe and the orbiter, continual coverage by the DSN would require two receiving networks.

Magnetometer. The magnetometer will measure the interplanetary magnetic field and the planetary field. Interaction between the solar field and the planetary field is also measured during passage of the bus through the planet magnetosphere. It is required to operate throughout the cruise phase and entry until bus destruction in the lower atmosphere of Venus.

The instrument consists of two separate units, a sensor and the electronics. For the spacecraft magnetic interference not to exceed 0.5 gamma at the sensor, the sensor must be deployed on a boom.

Bus spin is required within the range of 5 to 60 rpm and the 3 axes of the sensor must be positioned and maintained to within 1 deg (each sensor) of the X, Y and Z axis of the spacecraft.

The magnetometer experiment could not be flown on the probe bus and return meaningful scientific data without impacting the present design and the design of the large and small probes to a large extent.

The impact is in the form of magnetic control to reduce the level of the fields generated by the bus and the probes. The mass, volume, power, and telemetry requirements for this experiment could be accommodated in the present design along with a boom to deploy the sensor approximately 2.4 m (8 ft) from the solar array edge.

With this length boom, a comprehensive magnetic control program is required to reduce the spacecraft and probe fields to a meaningful limit. Some reduction of the control could be made if the boom was longer, however, the longer boom has other impacts on the design, for instance, unlike the magnetometer boom of the orbiter, the boom cannot be stowed above the

equipment platform due to the presence of the probes. The failure mode analysis for the boom if not deployed shows a 10 percent loss in solar power due to boom shadowing.

Magnetic calculations made on the spacecraft show that with a 2.4 m (8 ft) boom, the magnetic control costs would exceed \$1.3 M for a 0.5 gamma background.

#### Wind Velocity Measurement Study (EX8)

The purpose of this study is to examine alternative methods of measuring wind velocity and to compare their measurement capabilities versus their impact on probe design. Originally defined as a wind-drift radar/altimeter study, it was later broadened to include all wind velocity measurements after the wind drift radar was deleted from the nominal large probe payload and a transponder for use with DLBI/Doppler velocity measurements (DLBI stands for doubly differenced very long baseline interferometry) was added, in the October 1972 payload.

The uncertainties involved in measuring the wind via probe motion, in general, and by Doppler/DLBI and wind drift radar methods in particular have been calculated. As specific instrument designs are proposed these results should be reviewed and possibly expanded. This is especially true as the expected uncertainty in a given measurement is refined.

#### Measurement Objectives

To make meaningful estimates of the global atmospheric dynamics on Venus, any wind determination method must be able to define the wind speed to within 1 m/sec over an altitude range of 70 km-0 km. In addition, the probes should have:

- 1) Maximum latitude separation
- 2) Maximum longitude separation
- 3) Cover both sun and the dark side of the planet. In addition, since global wind patterns are of primary interest, local turbulences should be avoided. This implies that the probes should not be targeted near the terminator.

If an altimeter is not flown, the altitude (key to an interpretation of several experiments) can be determined, or defined in a number of ways:

- 1) Measure time, and probe velocity (DLBI and doppler) and calculate distance below blackout, or some other point.
- 2) Measure time, temperature, and pressure, calculate density, and use known aerodynamic relations to calculate a descent velocity; then proceed as in 1).

- 3) Measure time and acceleration, integrate accelerometer measurements to obtain a descent velocity (and possibly wind and turbulence measurements), and proceed as in 1).
- 4) Measure time, assume an atmospheric model, and correlate some property (i. e., temperature) with altitude, then simply measure that property and assign the corresponding altitude.

The primary goal of the wind velocity experiment is to contribute to understanding of the dynamics of the deep atmosphere by measuring wind speeds and determining the character of the atmospheric turbulence.

It would be very desirable to be able to measure wind velocity and altitude from the cloud tops to the surface (70 km to 1 km), not only for the large probe, but also for the small probes, in order to determine the complete wind profiles and gain the maximum information possible about the atmospheric circulation. The DLBI/doppler wind measurement technique which is carried in the baseline system inherently has this capability, which makes it very attractive if it proves feasible. The wind-drift radar was restored to the nominal payload of the large probe in the April payload definition, so that both measurement techniques are currently under consideration.

#### Probe Dynamics

Steady winds are the simplest atmospheric motions in terms of flight influence. Horizontal wind components introduce lateral translation of the probe but have no effect on descent or stability. Vertical wind components add directly to the descent velocity, or the altitude history is directly influenced.

A steady wind shear (constant derivative of horizontal wind speed with respect to vertical distance) introduces a very small inclination of the descending system and is most severe for a parachute-suspended capsule.

It is of interest to determine to what extent the small probes, and the large probe after parachute release, will follow the wind. Calculations have been made of the probe horizontal velocity error in response to wind shear, with results shown in Figure 3-22. The nominal wind shear, assuming a uniform decrease in wind speed from the 100 m/sec observed in the upper cloud layers (4-day rotation) to zero at the surface, is about a tenth of the value plotted, and since the velocity error is directly proportional to wind shear, it seems reasonable to assume that the probe velocity will be closely following the wind velocity most of the time. The maximum error at altitudes of 40 km and below would be 20 cm/sec. Figure 3-23 shows wind speeds reported by Venera 4, 7 and 8.

Another parameter of interest is the probe stability. The effect of gusts on the attitude of the large probe is shown in Figure 3-24. Assuming a gust of 9.1 m/sec (30 ft/sec) at an altitude of 43 km lasting for 30 sec,

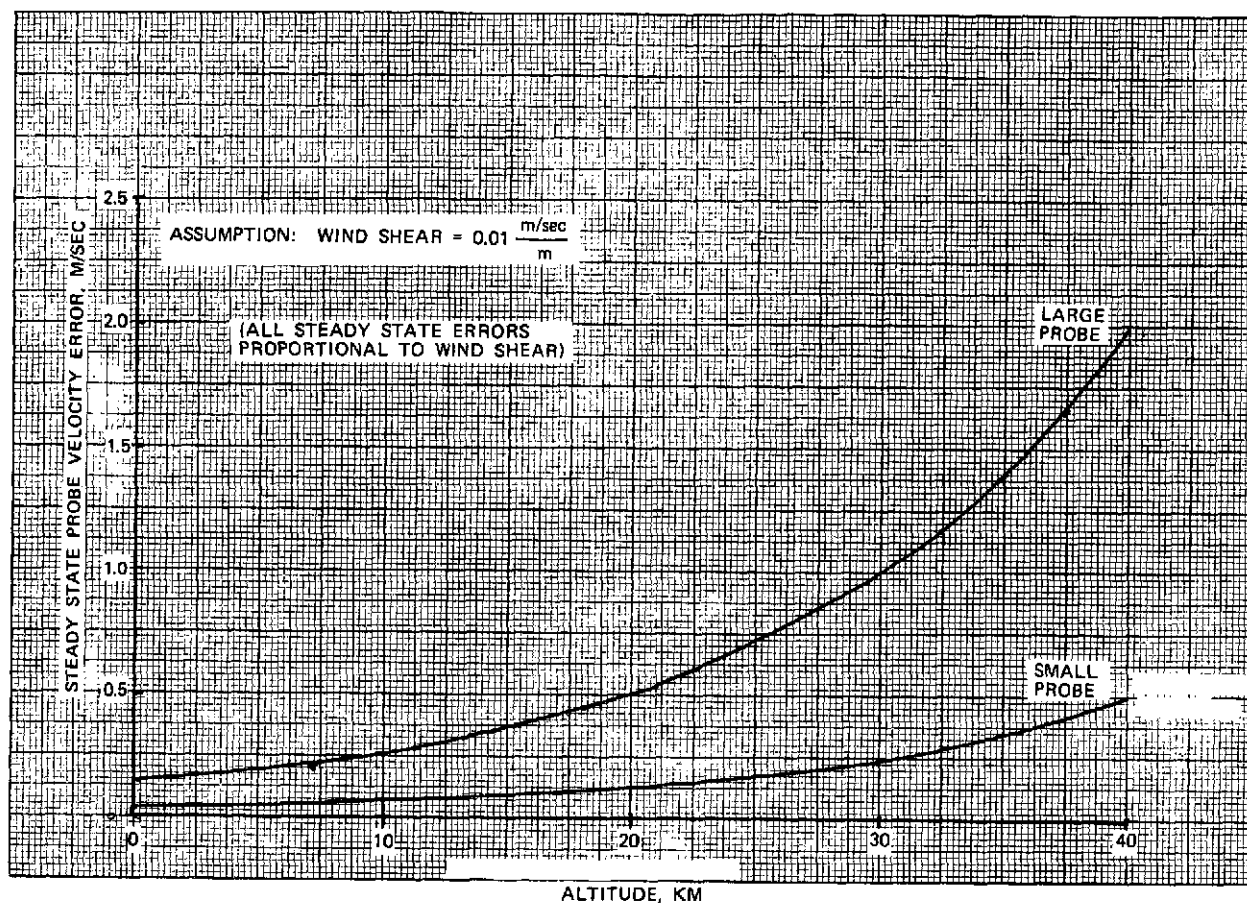


FIGURE 3-22. PROBE VELOCITY ERROR IN RESPONSE TO WIND SHEAR



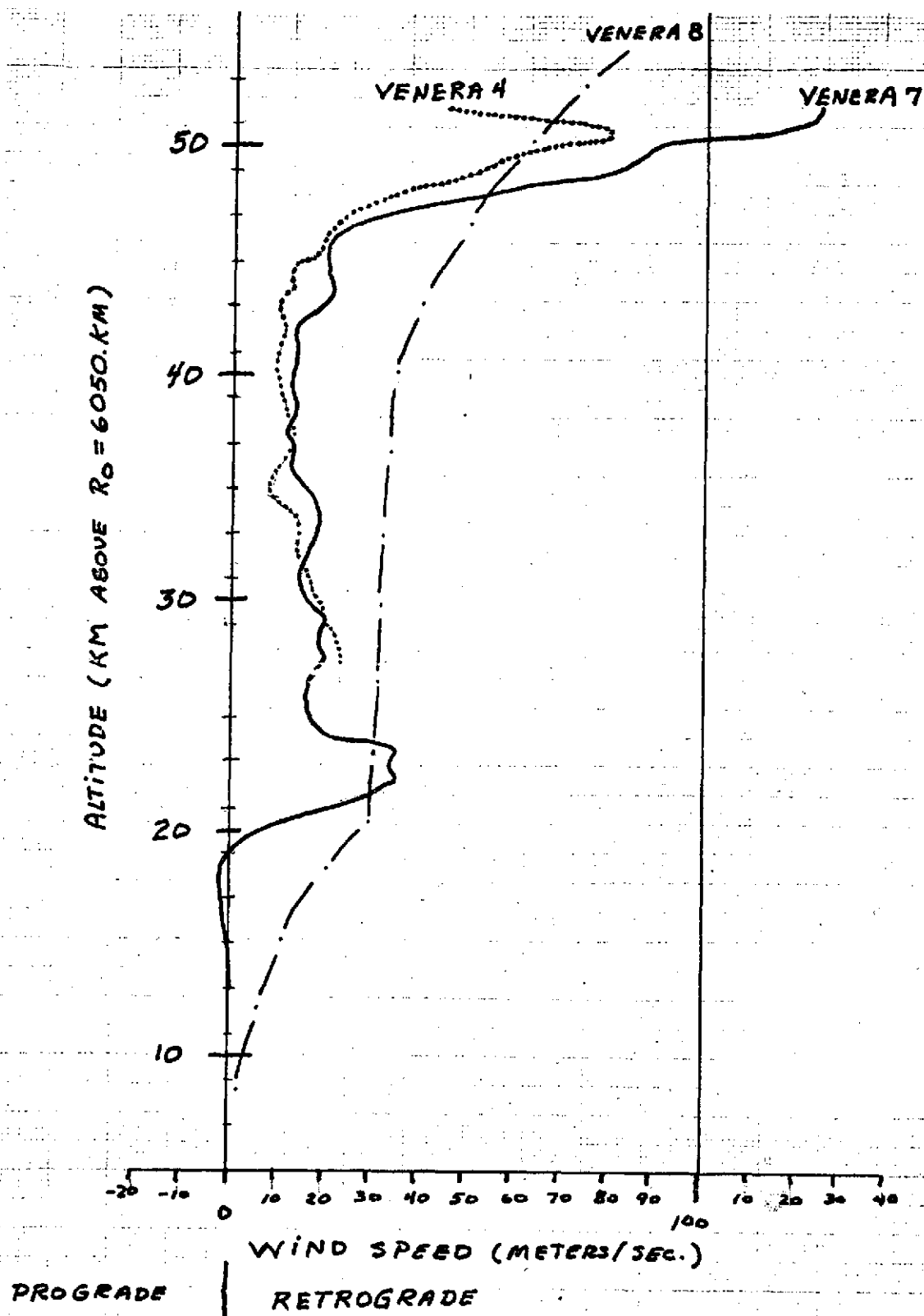


FIGURE 3-23. VENERA WIND SPEED MEASUREMENTS

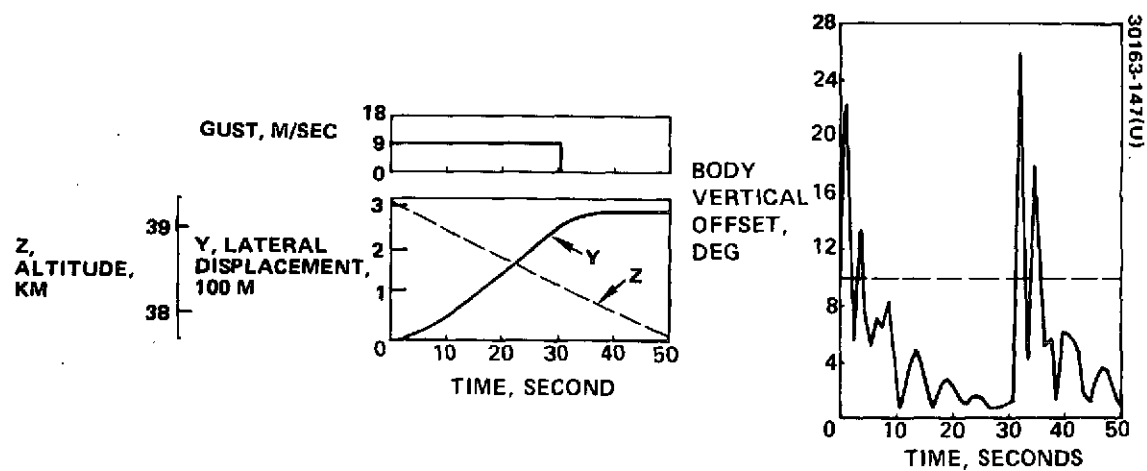


FIGURE 3-24. BASELINE RESPONSE TO GUST

the vertical offset of the probe is reduced to less than 10 deg (considered an acceptable upper bound) within a few seconds after the beginning and end of the gust.

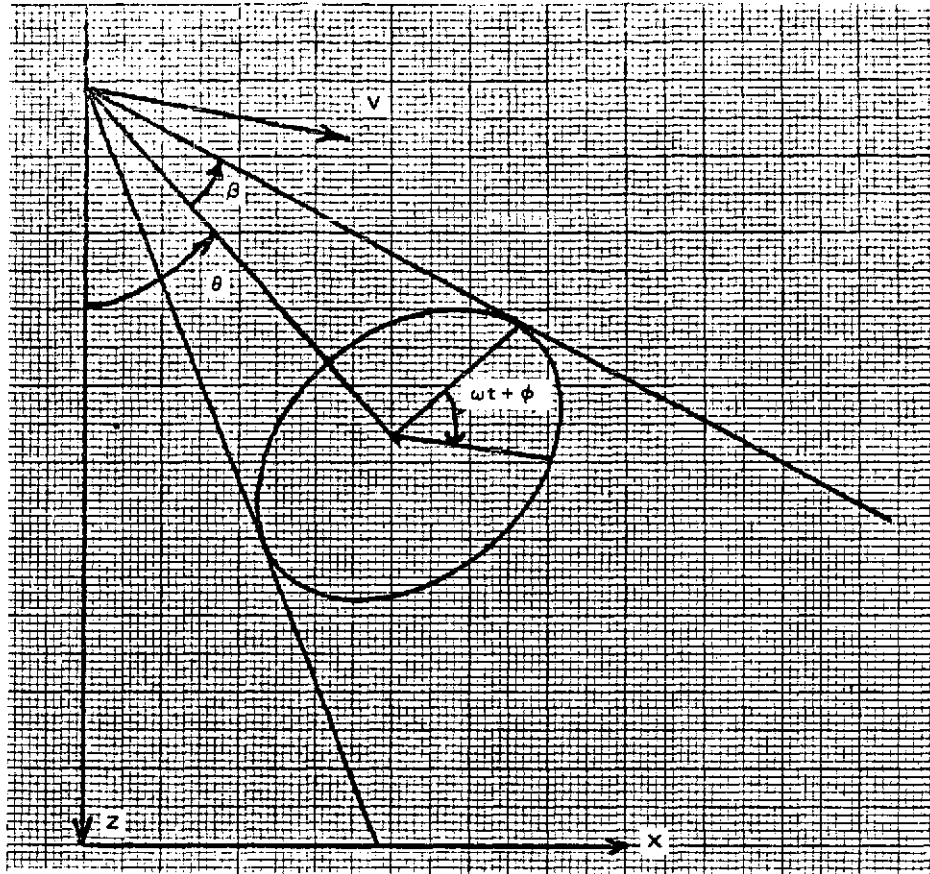
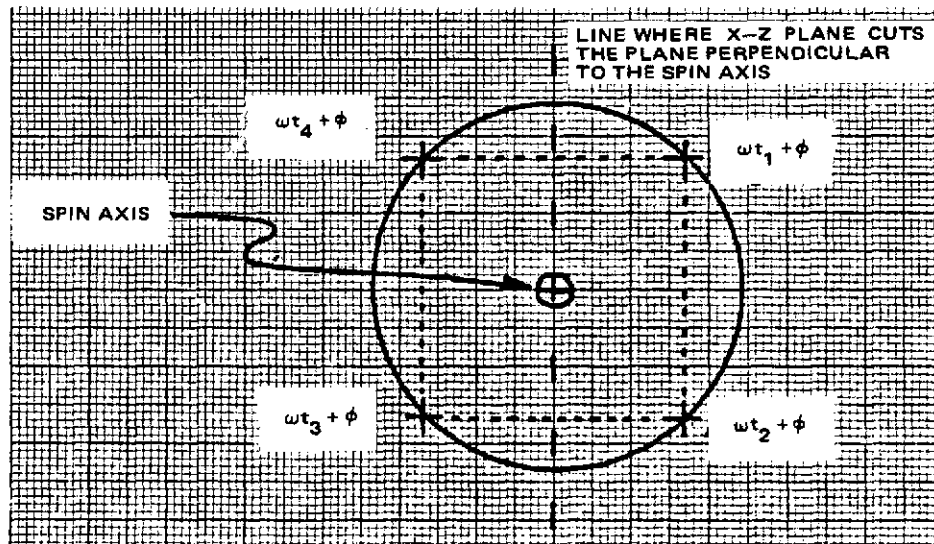
### Wind Drift Radar Measurements

Conceptually a velocity and altitude measurement of high accuracy is obtainable from a suitably designed radar. The question is, can a radar of suitable accuracy be obtained which meets the requirements of power, weight, size, cost, and does not generate extreme spacecraft requirements?

Table 3-35 lists some radar connected concepts and briefly describes them.

TABLE 3-35. WIND DRIFT RADAR CONCEPTS

Approach	Comments
<u>Radar Modulation</u>	
FMCW (frequency modulated continuous wave)	FMCW is a technique of modulating the radar frequency to obtain a range measurement. With a ramp function for the modulation, the range is related to the peak frequency measured. Velocity measurements are made using the doppler shift.
ICW (interrupted continuous wave)	ICW embodies the idea of pulsing the radar signal and timing the return signal to measure the range. Velocity is measured via the doppler effect. This approach requires a high peak power, but a much lower average power.
<u>Radar Beam Geometry</u>	
Single offset beam	A radar beam offset from the spin axis will scan the terrain below, enabling one to measure velocity (via doppler) and range (via either ICW or FMCW). This approach is considered in more detail here.
Multibeam	This idea can be used on a spinning platform but does not require one. It was used successfully on the Surveyor and Apollo programs. Doppler and range data are obtained from each beam and combined to give the spacecraft velocity and position.

a) BEAM OFFSET  $\beta$  FROM SPIN AXIS TILTED  $\theta$  TO VERTICAL

b) MEASUREMENT POSITION DURING SPIN CYCLE

FIGURE 3-25. SINGLE BEAM RADAR GEOMETRY

The requirements generated by the radar on the spacecraft have been briefly examined. The questions of weight, power, volume, and cost have been left to the detailed radar studies currently being completed by the Singer-Kearfott Company. Figure 3-25 illustrates the geometry of a single beam radar offset from the spin axis by the angle  $\beta$ . The angle  $\theta$  is the angular displacement of the spin axis from the local vertical. The velocity of the probe is  $V$ . The angular velocity is an arbitrary phase angle  $\phi$  and is chosen so that at  $t = 0$  it is the plane of the paper. Measurements at 90 deg intervals ( $t_1$  through  $t_4$ ) are also shown.

The multibeam approach is included in this analysis by requiring the measurements shown on the circle in Figure 3-25 to occur simultaneously.

One probe requirement that is immediately clear, is the need for an angular reference if north-south, east-west definition is important. This implies the need for maintaining the sense of the probes inertial coordinate system, even while that system is aligned with the spin axis and the spin axis is changing direction as the probe descends. This can be illustrated by considering Figure 3-25. In addition to knowing what the relation is between the probe coordinates and the local north, the probe X axis must remain in the plane of the paper as the probe falls to the surface of Venus. (To account for all possible motions, nutations, etc., should be allowed, but even then the requirement is for a constant reference direction with respect to the planet's surface.)

At present there does not appear to be a great concern in measuring the wind velocity with respect to the local Venusian coordinates. Perhaps this comes about because of the added complexity necessary to obtain an absolute angular reference, and the notion that wind speed is more meaningful than wind direction. If this is so, the requirement for an angular reference is relaxed. Future missions, however, will almost certainly be concerned with a measurement of the wind's direction with respect to local coordinates.

Even if an absolute angular position is not required, a single beam radar will require an angular rate measurement. In processing the data to obtain descent and wind velocities it is important to have accurate knowledge of the relative angular position of the beam during each measurement. In Figure 3-25 this appears as the angles  $\omega t_1 + \phi$ ,  $\omega t_2 + \phi$ , etc. This implies a measurement of time and  $\omega$ , the angular rate.

The results of a detailed analysis of several methods of data processing are presented in Figures 3-26 through 3-28. In order to present wind speed uncertainties in m/sec, rather than parametrically, the data presented in Figure 3-26 was used. This Figure represents a realistic descent velocity versus altitude, and a wind profile that is "reasonable". The wind model is taken simply for convenience, and is not based on any theoretical or experimental data.

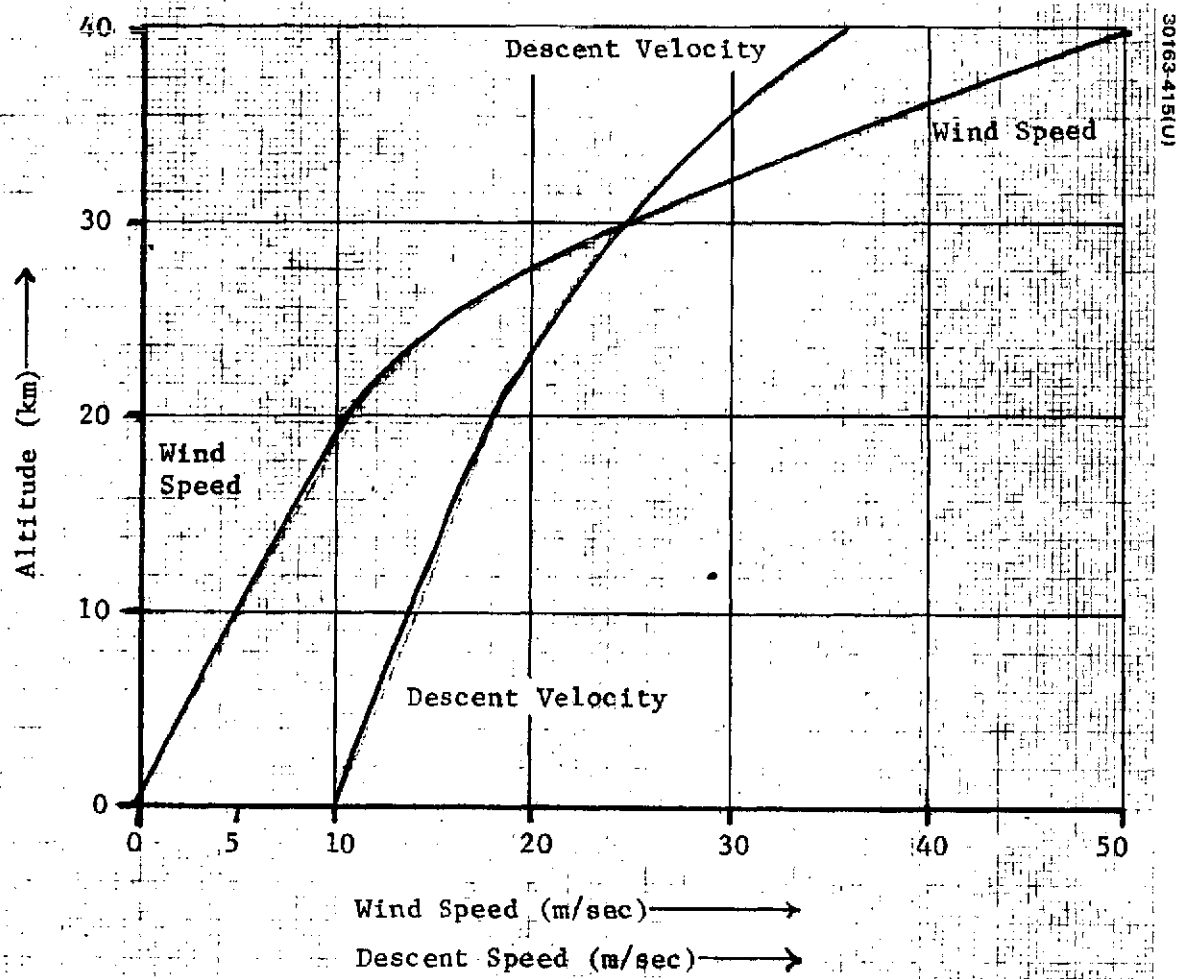


FIGURE 3-26. DESCENT VELOCITY AND WIND SPEED MODEL

Figure 3-27 presents the results when the radar data is processed to yield only the descent velocity and a wind speed. Reducing the spin axis offset angle  $\theta$  greatly improves the accuracy of both wind speed and descent velocity. (A change in squint angle  $\beta$  has a very small change in the accuracy accuracy).

A second method of processing which has the potential of yielding wind direction (provided an accurate angular rate is provided) results in the uncertainties plotted in Figure 3-28. Instead of measuring the maximum and minimum Doppler, the radar measures the Doppler velocity at four points in the spin cycle and subtracts alternate measurements.

The uncertainty in the wind measurement can be reduced by averaging over several measurements. In this case the uncertainty is a function of the number of spin cycles averaged over as shown in Figure 3-28. Also, shown is the departure of the average wind speed from the peak wind speed for wind shears of 0.01 and 0.05 m/sec/m during the averaging interval. Clearly an optimal averaging period exists for a given set of descent parameters.

It is conceivable to use radar data to calculate  $\theta$  and thereby reduce the uncertainty in wind speed. This measurement, however, would require a more complex processing scheme, and perhaps a multibeam radar.

As mentioned earlier an angular rate measurement is needed for the wind speed determination whether or not an absolute angular position is required. Since an external sun sensor cannot be depended on to provide angular position and/or rate (due to the assumed cloud cover) some internal measuring device is required.

The conventional spring-restrained rate gyro would be marginally capable of providing 1000 deg/h rate accuracy. The more accurate rate integrating gyro, however, could provide both rate and, by digitally integrating the torquer signal, the angular position information. Angular position accuracy to 20 deg or so should be achievable with integrating gyros of only moderate accuracy.

The most stringent environmental conditions is the 500 to 600 g deceleration during entry. However, during the remainder of the descent the acceleration is expected to be around 1 g. Accordingly, gyro performance during this period of greatest interest should not be adversely affected by g-loadings.

In this section the uncertainties involved in measuring the wind with a radar have been discussed. The basic idea is to measure the probe velocity, assuming that the probe closely follows the wind. This assumption was examined and is believed valid. The main probe impacts are involved with the addition of at least a rate gyro, and the uncertainty introduced by the deviation of the spin axis from the local vertical ( $\theta$ ). With reasonable care the uncertainty in wind speed for the models assumed should be less

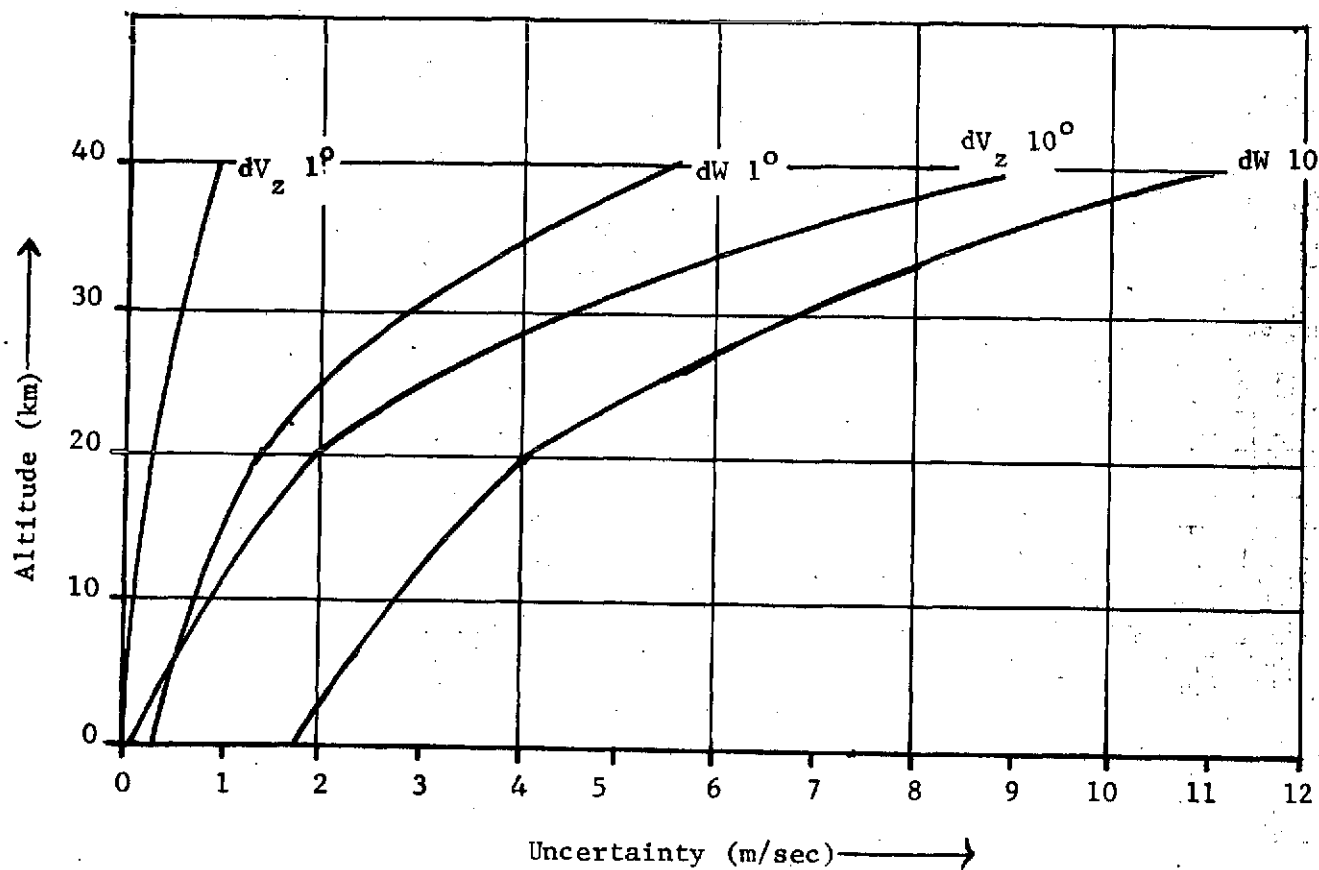


FIGURE 3-27. UNCERTAINTIES IN WIND SPEED, W, AND DESCENT VELOCITY,  $V_z$ , FOR 1 AND 10 DEGREE OFFSET ANGLES



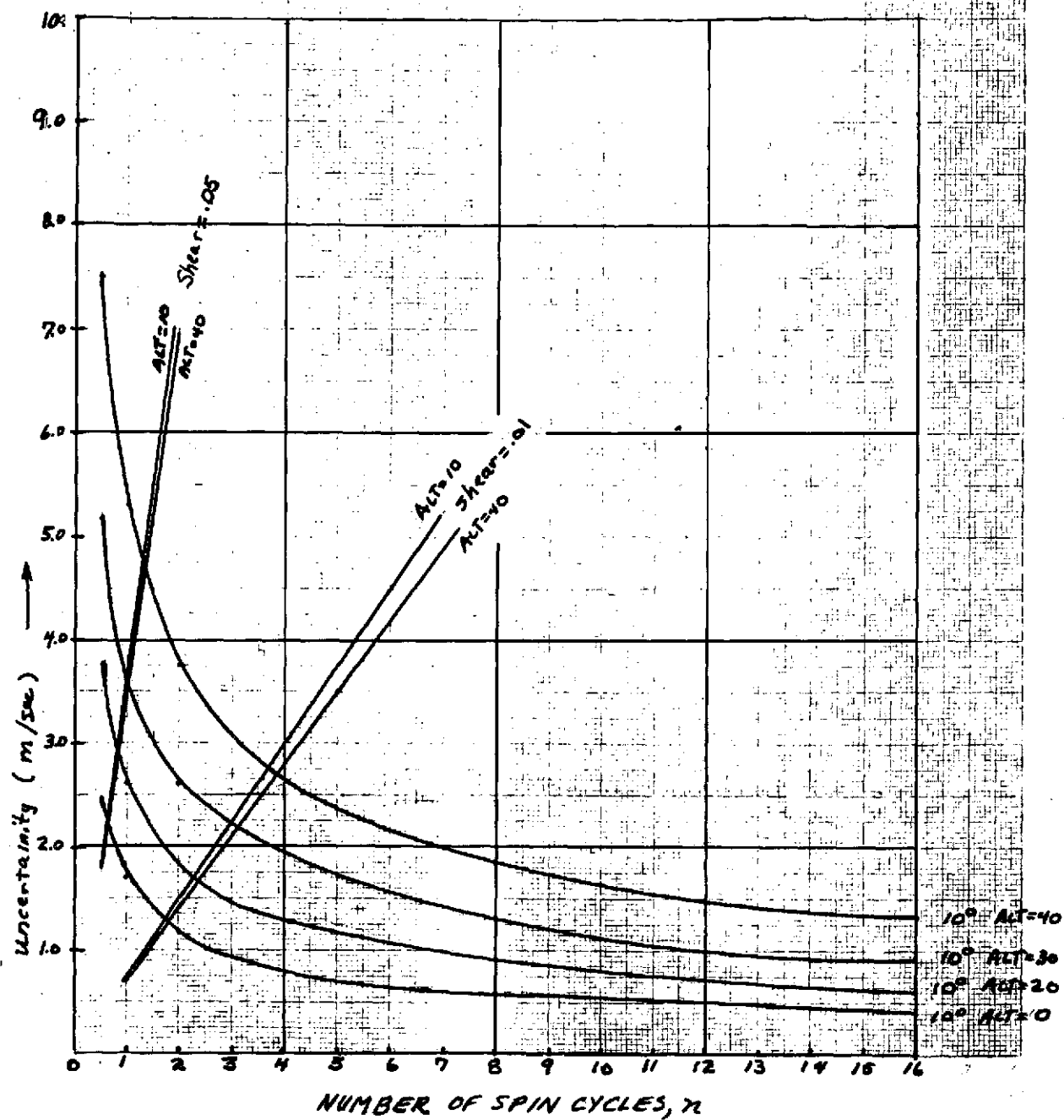


FIGURE 3-28. UNCERTAINTY IN WIND MEASUREMENTS

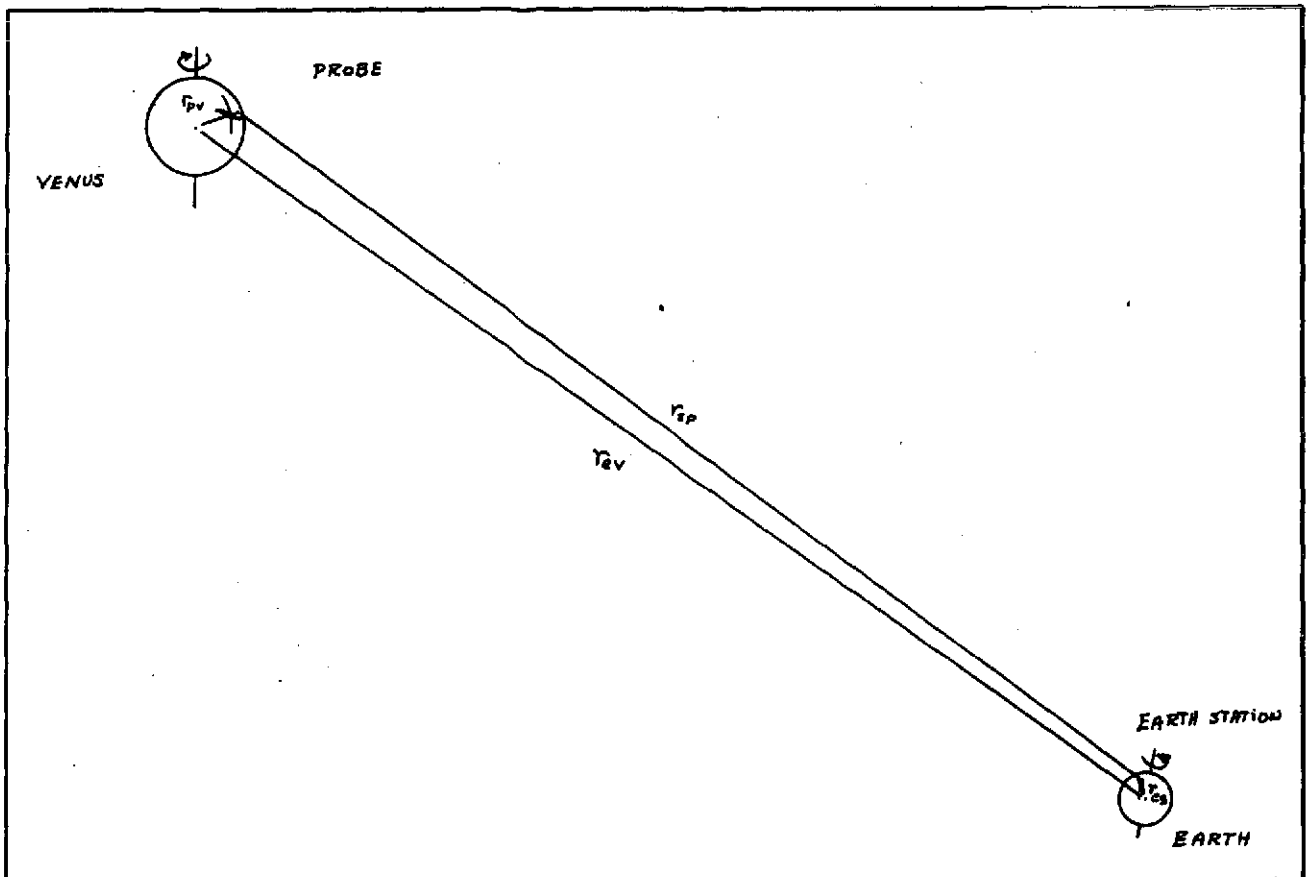


FIGURE 3-29. EARTH PROBE GEOMETRY FOR DLBI/DOPPLER ANALYSIS

than 3 m/sec. Only with a very stringent requirement on  $\theta$  ( $\theta \leq 1$  deg) or the measurement of  $\theta$  can the uncertainty in wind speed be made less than 1 m/sec for all altitudes. (Even then a wind shear of 0.05 m/sec/m would introduce an uncertainty greater than 1 m/sec.)

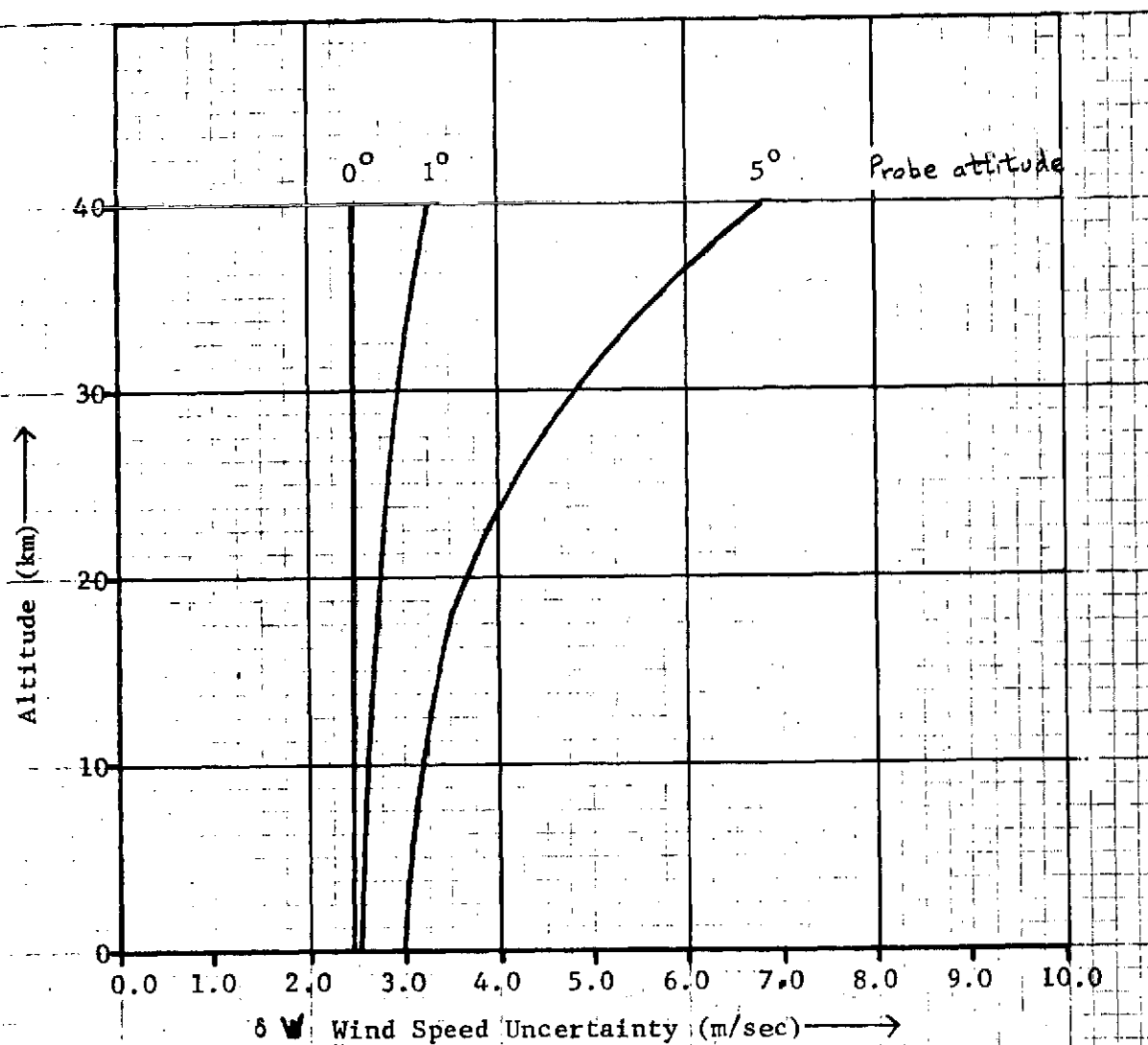
### DLBI/Doppler Measurements

If the velocity vector of the probe can be measured very accurately with respect to an earth station, and the velocity of the earth station known with respect to the center of earth, and the velocity of Venus's center with respect to the center of the earth, simple vector addition can determine the velocity of the probe with respect to Venus. Again, assuming the probe "follows" the wind, one can construct the horizontal and vertical components of velocity to infer the horizontal wind. By comparing the measured vertical speed with theoretical calculations of descent velocity, vertical winds can be inferred.

Velocity of the probe in the earth-station-probe direction, is inferred from Doppler measurements. Velocity components parallel to vectors from one earth station to another are measured via very long baseline interferometry. If two separate transmitting sources are near Venus, a symmetric double difference technique can be used to remove systematic propagation errors in the relative velocities of the two sources. This gives rise to the requirement for the probe bus to enter the atmosphere after the probes, and the bus's velocity and position during this time be well known. A detailed analysis of the errors associated with the DLBI technique is being done by I. Shapiro, et al., at M.I.T. The velocity of the earth station with respect to the center of the earth is simply the velocity caused by the rotation of the earth. The corresponding rotationally caused velocity on Venus is also known. The geometry of the situation is shown in Figure 3-29.

To get some idea of the uncertainties in the final probe velocity without running detailed computer parameter studies, a simpler two-dimensional case has been considered. The uncertainties in the  $\Omega \times r$  terms are small for both earth, and Venus.

If it is assumed that the DLBI and Doppler uncertainties are both 1 m/sec, the maximum wind uncertainty for zero probe velocity occurs at a 45° latitude. Then the wind uncertainty equals 2.46 m/sec for exact knowledge of the landing location. Figure 3-30 shows how this uncertainty changes as a function of altitude assuming the wind altitude profile shown. The curves labeled 1 deg and 5 deg correspond to uncertainties in entry angle  $\gamma$  of 1 and 5 deg. These correspond roughly to uncertainties in the impact parameter of 30 km and 300 km, respectively.



## Assumptions

$$\delta v_z = \delta W = 1 \text{ m/sec}$$

$$\delta W = \sqrt{\delta v^2 + \delta v_z^2}$$

$$\text{Latitude} = 45^\circ$$

## Wind Uncertainty

Alt.	0°	1°	5°
40	2.46	3.15	6.85
30	2.56	2.82	4.76
20	2.46	2.68	3.64
10	2.46	2.60	3.26
0	2.46	2.56	3.00

FIGURE 3-30. WIND UNCERTAINTY VERSUS ALTITUDE AS A FUNCTION OF PROBE ATTITUDE

For a transponder, the frequency being Doppler shifted is well known; however, for an oscillator on a small probe, this frequency is not as well known. The measured frequency in this case is

$$\nu = f_{\text{osc}} \left( 1 + \frac{T}{c} \right)$$

where

$T$  = the Doppler velocity (the velocity along the line of sight)

$\nu$  = the measured frequency

$f_{\text{osc}}$  = the oscillator frequency

The uncertainty in velocity is related to the uncertainty in oscillator frequency as

$$\delta T = c \frac{\delta f_{\text{osc}}}{f_{\text{osc}}}$$

This is shown in Figure 3-31. For a 1 m/sec uncertainty in the Doppler measurement, the oscillator frequency should be known to within one part in  $10^8$ . Table 3-36 lists several alternate means of determining the oscillator frequency.

TABLE 3-36. POSSIBLE METHODS OF DETERMINING OSCILLATOR FREQUENCY

- |  |
|--|
| <ul style="list-style-type: none"> <li>• A priori knowledge (<math>\sim 10^{-6}</math>)</li> <li>• Calibrate from orbit determination at entry (<math>\sim 10^{-7}</math>)</li> <li>• Calibrate using temperature and pressure measurements to calculate a descent velocity</li> <li>• Calibrate before probe release when Doppler trajectory is available (<math>\sim 3 \times 10^{-8}</math>)</li> <li>• Calibrate oscillator after landing</li> </ul> |
|--|

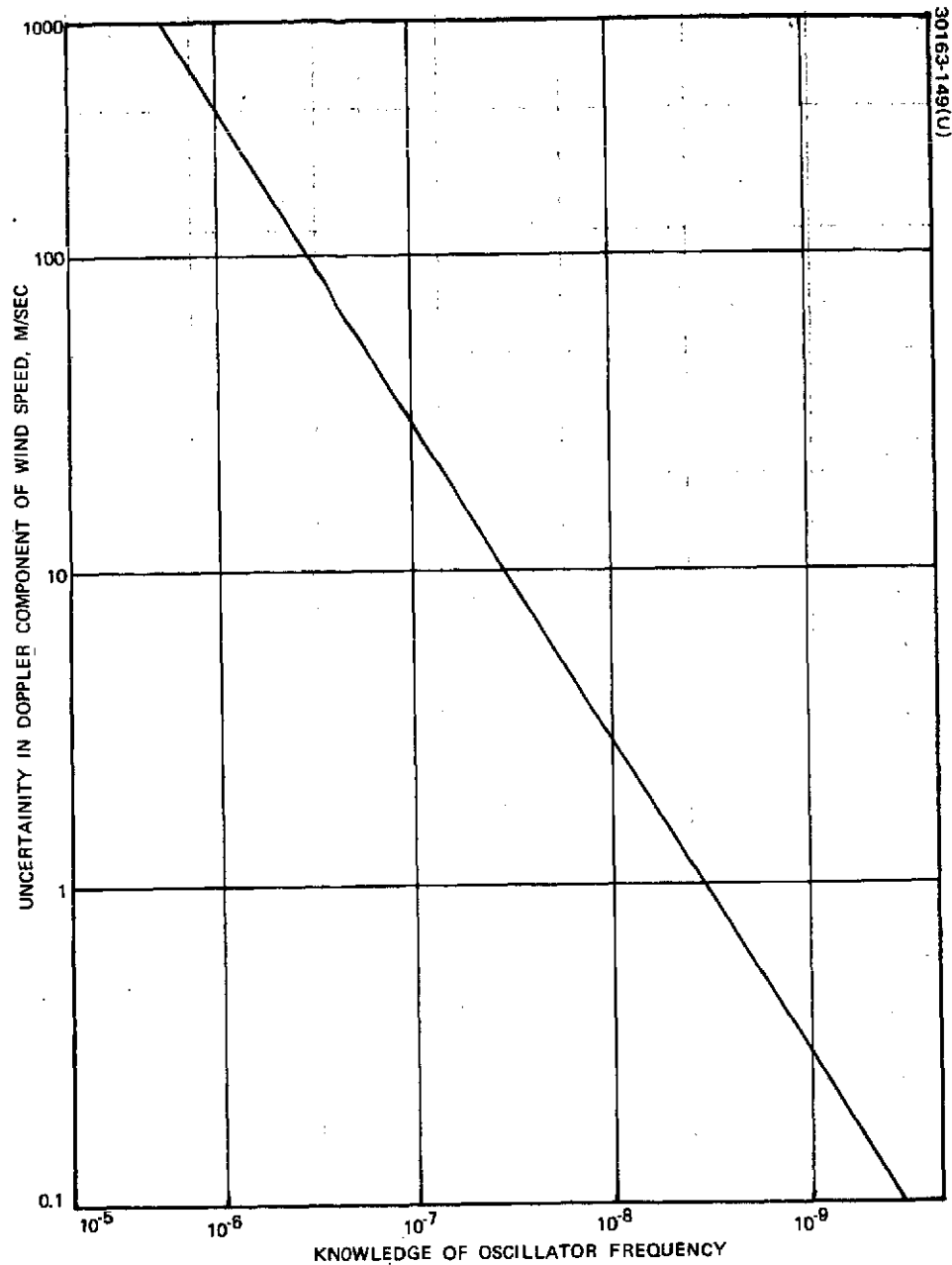


FIGURE 3-31. UNCERTAINTY IN DOPPLER VELOCITY VERSUS OSCILLATOR UNCERTAINTY

At present, the oscillator frequency is specified as known to one part in  $10^{-6}$  and stable to one part in  $10^9$ . This does not appear adequate in terms of the Doppler uncertainty involved.

Just before entry, the small probe velocity will be uncertain by about 40 m/sec from orbit determination analysis. Thus

$$\frac{\delta f_{\text{osc}}}{f_{\text{osc}}} = \frac{40}{3 \times 10^8} \sim 10^{-7}$$

If one is willing to assume there are no up or down drafts, the descent velocity can be calculated from temperature and pressure measurements and a knowledge of the equation of state of the atmosphere. Figure 3-32 shows the accuracy achievable in the two-dimensional case by using the equation

$$V_x \cos \gamma + V_z \sin \gamma = V_{\text{descent}} = \sqrt{\frac{g M}{C_D A \rho}}$$

where  $g$  is the acceleration due to gravity,  $C_D$  is the drag coefficient,  $M$  is the mass,  $A$  is the area, and  $\rho$  is the density constructed from the temperature and pressure measurements and the equation of state. In Figure 3-32 a 1 percent uncertainty in mass, a 10 percent uncertainty in drag coefficient, and 5 percent uncertainty in density have been assumed. The total uncertainty is directly proportional to the sum of the individual uncertainties in mass, drag coefficient etc., so these curves hold for any group of uncertainties which sum to 16 percent.

If the oscillator frequency is measured just before probe release, it is possible that the frequency uncertainty could be made equal to three parts in  $10^8$ . This would, however, require both sequence and hardware modifications.

A post landing measurement of oscillator frequency would (assuming no shift due to impacting on the planet) provide a very accurate oscillator frequency determination  $\sim 10^{-10}$ .

In summary then, doppler measurements of a stable oscillator imply an oscillator stability and accuracy of one part in  $10^9$  for a 0.3 m/sec uncertainty in the doppler component of wind velocity, and of the various methods discussed, using the descent velocity provides the best calibration with the least impact on the probe design.

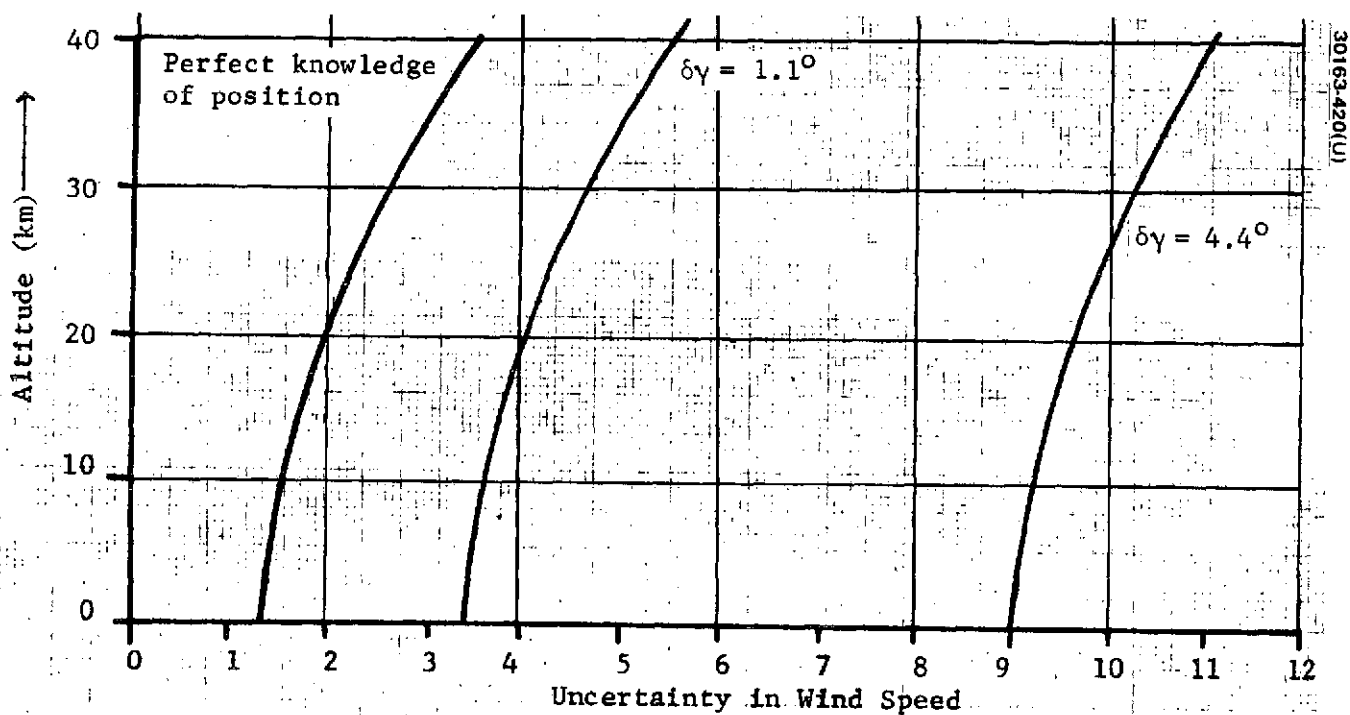


FIGURE 3-32. UNCERTAINTY IN WIND SPEED AS A FUNCTION OF POSITION  
UNCERTAINTY USING THEORETICAL DESCENT VELOCITY TO CALIBRATE  
OSCILLATOR



A full error analysis on the DLBI is being completed at MIT by I Shapiro et al. His analysis indicates DLBI uncertainties of less than  $100 t^{-1} \text{m/sec}$  where  $t$  is the resolution time. An optional measuring interval can be chosen for a given shear by setting.

$$\frac{100}{t} = \frac{1}{2} (S W t)$$

Where  $S$  is the wind shear,  $W$  is the wind speed, and  $t$  is the time.

$$t = \sqrt{\frac{200}{SW}}$$

The corresponding uncertainty for this optional time is

$$\Delta = \sqrt{50 SV}$$

These are shown in Figure 3-33.

#### Experiment Integration Plan (PL 10)

This plan describes the procedures by which Hughes Aircraft Company (HAC) will manage the science integration activities for the Pioneer Venus program.

The HAC activity involves the design, development, integration and test of the spacecraft, probes and their respective subsystems. NASA/ARC will provide the science instruments to HAC to integrate and test with the spacecraft, probes and their respective subsystems to meet the overall system requirements.

To accomplish this task, a well defined plan clearly describing responsibilities, integration procedures, specifications and schedules must be prepared and approved by those concerned parties prior to program go-ahead.

This activity is part of the Project Development Plan, and the Experiment Integration Plan appears in Volume 15 of the final report. It is summarized here.

The Hughes plan to manage experiment (or science) integration activities is to establish a single Hughes scientific payload management office reporting directly to the Program Manager as part of the Program Office team. This office will have the responsibility for directing and controlling all activities concerned with science experiments for Hughes and General Electric, and will provide an effective coordination point with the NASA/ARC experiments manager.

The office will have Hughes and GE program management backing for all matters concerning experiments and science requirements and will include a staff of experiment integration specialists with proven experience in the necessary technical disciplines.

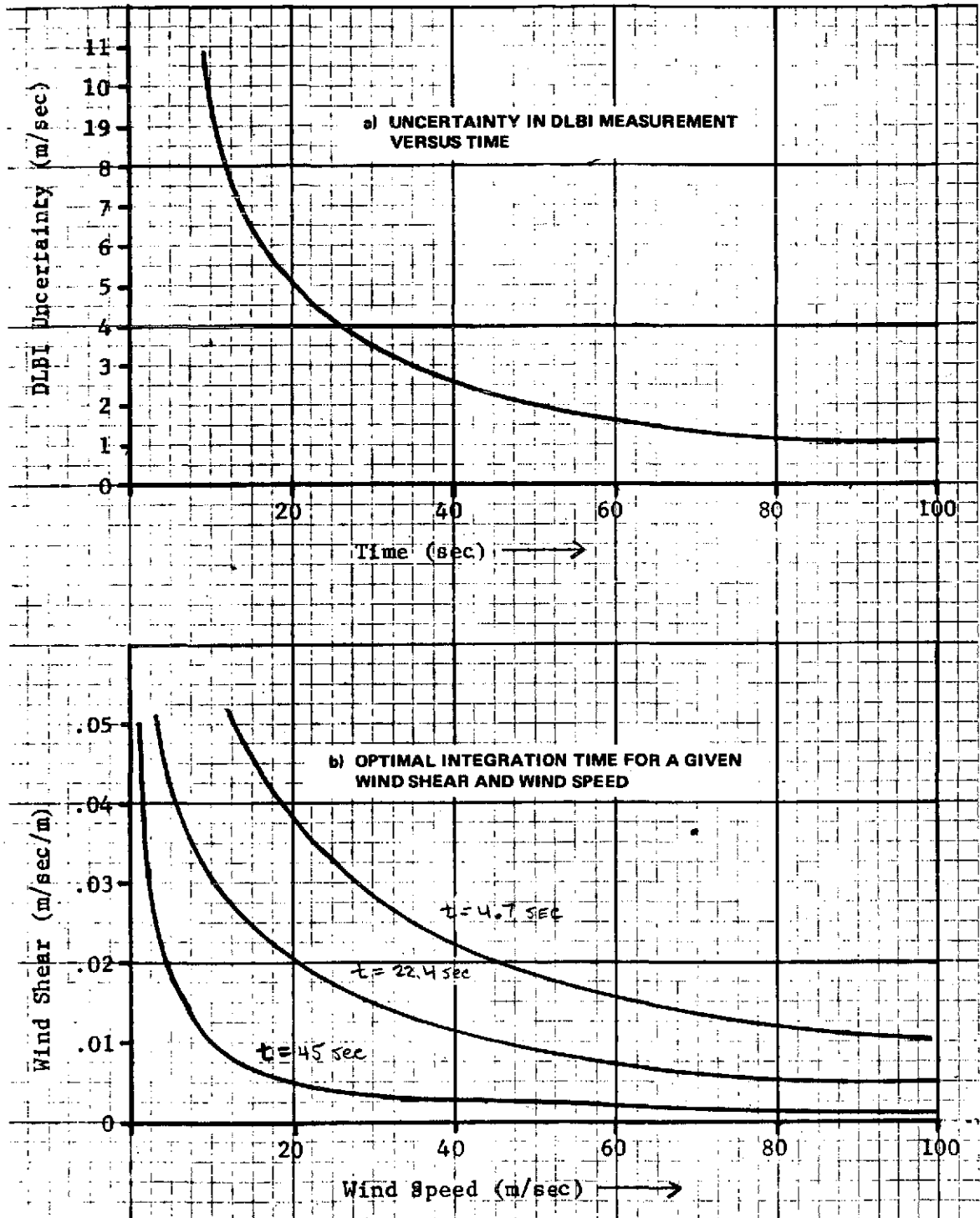


FIGURE 3-33. ERROR ANALYSIS OF DLBI UNCERTAINTY

The manager of this activity will have technical and managerial experience directly applicable to experiment integration activities. He will be responsible for maintaining sensitivity to the scientific objectives throughout the Hughes and General Electric organizations and ensuring cooperation with the NASA/ARC Pioneer Venus Project/Experiment offices.

All coordination with the scientific community and/or instrument developers will be with this office. Hughes recognizes NASA/ARC responsibilities for science experiments and the need for technical control during development of the instruments and as such will coordinate all technical contacts with experimenters to the extent and control required by NASA/ARC.

General Electric's subcontract with Hughes is for the deceleration module which includes the heatshield, structure, parachute, and parachute deployment system. General Electric is under the technical direction of the Hughes Probes manager. Thus, Hughes has design responsibility for all areas interfacing with the science instruments. This minimizes the number of organization/people involved in interface design decisions and results in a more efficient and effective operation.

The Experiment Integration Office will define, in association with System Engineering, the system and mission requirements derived from science requirements. They will also perform those tasks associated with experiment interface engineering as shown in Figure 3-34. This approach provides a central activity in support of HAC system and subsystem areas and prevents ambiguity in disseminating requirements and a focal point for resolving instrument accommodation problems that can originate in any area at HAC or requested by NASA/ARC.

The office will be manned by a small staff of science payload integration specialists who will focus on integration of instruments in the spacecraft and probes and maintain a surveillance within HAC to insure these objectives are met and not overlooked. The need to understand the science objectives and requirements is necessary to accomplish this primary task.

The effectiveness of this office will be strongly related to the personnel selected for this task not the quantity. To summarize, the key functions of the Experiment Integration Office are:

- 1) Define science requirements as applicable to system design
- 2) Support mission/system design
- 3) Support integration, assembly and test
- 4) Maintain interface requirements
- 5) Resolve accommodation problems
- 6) Support NASA/ARC experiments office

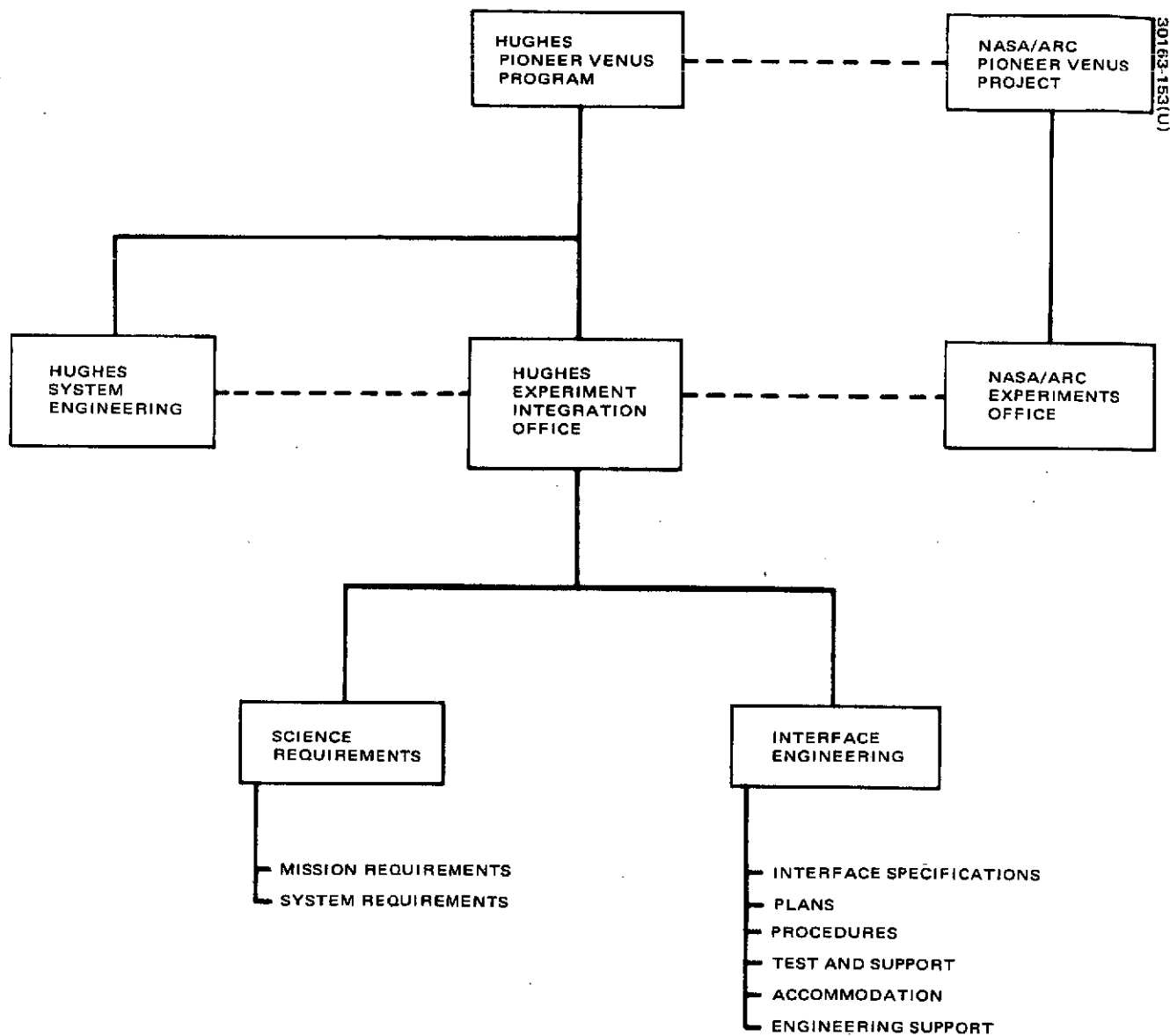


FIGURE 3-34. EXPERIMENT INTEGRATION OFFICE ORGANIZATION

## Probe Spacecraft/Experiment Interface Specification (SP 4)

This specification defines the spacecraft side of interfaces between the scientific experiments and the probe/spacecraft. In particular, this specification is divided into four parts as follows:

- 1) Defines the characteristics of the probe/spacecraft which are pertinent to all the scientific instruments and the common requirements of the probe bus, large probe and small probes. Any of the applicable common requirements in subsequent experiment interface specifications; paragraphs 2), 3), and 4) will be referenced to this specification (probe spacecraft/experiment specification).
- 2) Defines the characteristics of the probe bus pertinent to the scientific experiments and the requirements of the probe bus on the experiments (probe bus/experiment interface specification).
- 3) Defines the characteristics of the large probe pertinent to the scientific experiments and the requirements of the large probe on the experiments (large probe/experiment interface specification).
- 4) Defines the characteristics of the small probe pertinent to the scientific experiments and the requirement of the small probe on the experiments (small probe/experiments interface specification).

A draft of the experiment interface specification document appears in Volume 16.

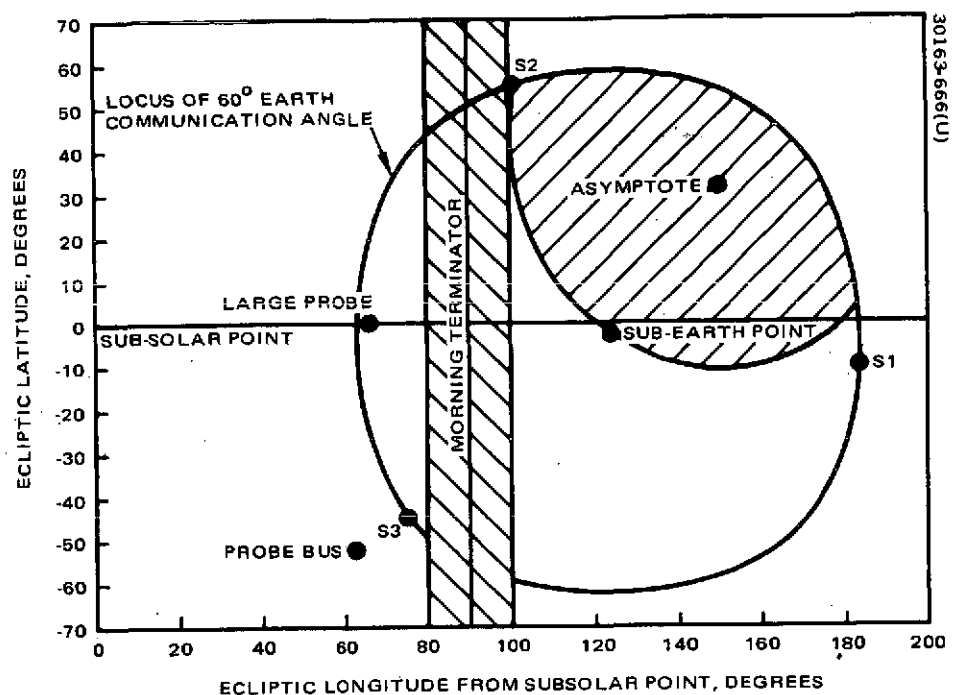


FIGURE 3-35. ATLAS/CENTAUR PROBE TARGETING

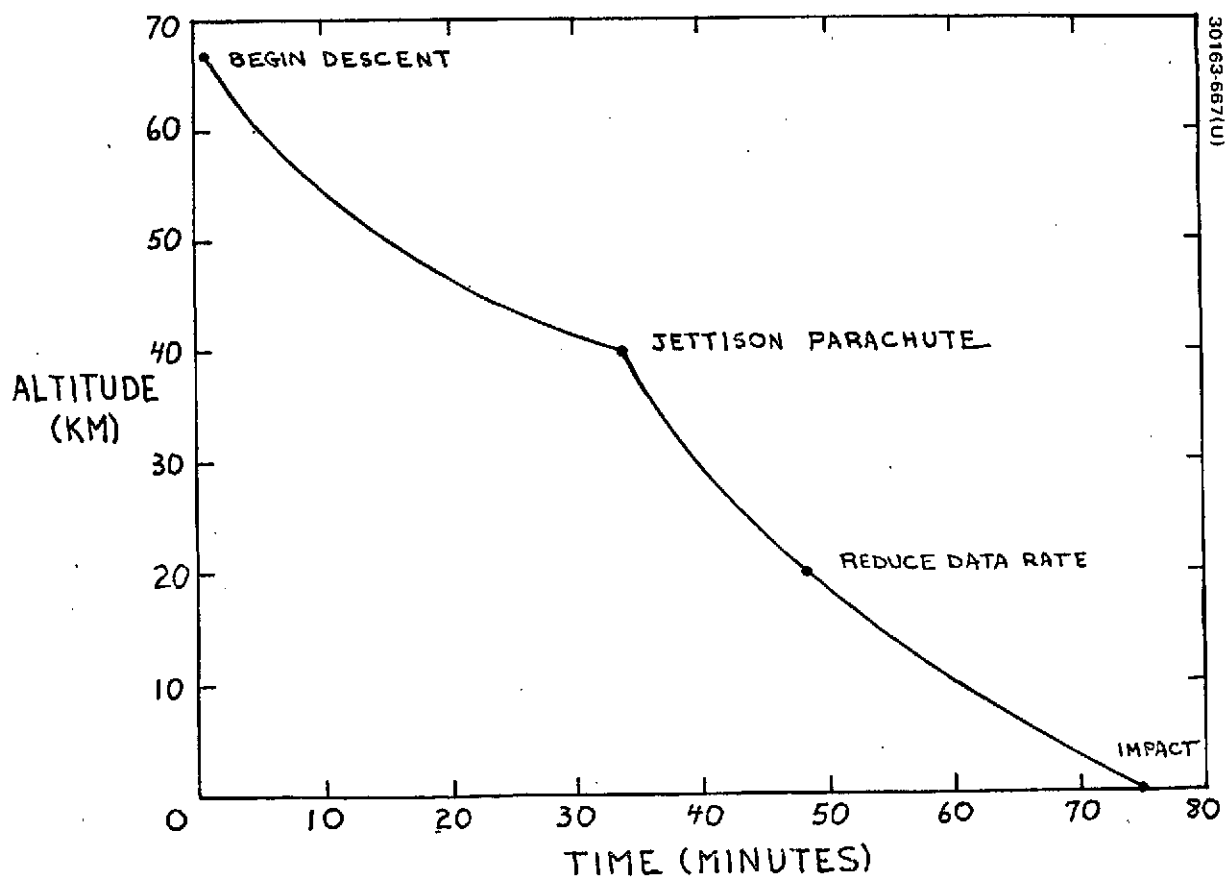


FIGURE 3-36. LARGE PROBE DESCENT PROFILE

### 3.4 SCIENCE PAYLOAD ACCOMMODATIONS

The problems associated with integrating all nominal\* science payload instruments together compatibly in the probes and probe bus will be discussed in this section, with the primary focus on the Atlas/Centaur baseline (April 1973). The final Atlas/Centaur baseline in response to the June RFP was not available at the time of completion of this final report; thus the accommodation discussions here are interim in nature. Accommodation of the final Atlas/Centaur payload will be discussed in the technical proposal.

At the midterm review the major emphasis was on accommodation of the Thor/Delta payload. Although the discussion of instrument accommodation here will be in terms of Atlas/Centaur, for completeness and continuity with earlier studies the Thor/Delta configuration will also be shown.

Before considering the specific accommodation of science instruments in the large probe, small probe, and probe bus, it is appropriate to point out some key system requirements driven by the experiments. These include a flexible targeting capability for the large and small probes and the probe bus, a descent time optimized for science data return, and a spin rate for the large probe compatible with wind/altitude radar requirements.

The mission sequence has been discussed in Section 3.1, with release of the large and small probes from the probe bus 20 days prior to entry. Figure 3-35 shows a representative targeting for the 1978 Atlas/Centaur mission which has the desired characteristics of 1) a maximum entry angle of about -60 deg (with the minimum about -20 deg ), 2) a vertical descent communication angle of 60 deg or less, 3) impact points at least 10 deg away from the terminator, 4) a maximum impact latitude dispersment, 5) a maximum impact longitude dispersment, 6) the large probe on the dayside as near to the subsolar point as consistent with the communications angle constraint, and 7) the probe bus at as small an entry angle as possible to maximize science observation time. The Hughes design has the capability of targeting the small probes anywhere within the locus of the 60 deg earth communication angle.

#### Large Probe

The Atlas/Centaur large probe nominal payload was presented in Table 3-6. The descent trajectory is shown in Figure 3-36, from the time of parachute deployment. With the parachute jettisoned at 40 km, the total descent time is about 75 minutes. At 20 km the data rate is reduced, because of increased signal attenuation in the lower atmosphere. Operating details for the science instruments are given in Table 3-32. The only instrument requiring probe spin is the wind altitude radar. Science data sampling requirements as requested by NASA/ARC are shown in Table 3-33; the data rate allocations in Table 3-34 are those provided by this design. As can be seen in the tables, the required data rate is met or exceeded in all cases.

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\* Accommodation of the other candidate instruments has been considered in Study Task EX1 and is discussed in Section 3.3.

TABLE 3-32. OPERATING DETAILS OF LARGE PROBE INSTRUMENTS

Instrument	Operating Altitude, km	Spin, rpm	Squib Activated Events	Remarks
Temperature gauge	67 to 0	Any	—	Data stored during entry
Pressure gauge	67 to 0	Any	—	
Accelerometer	150 to 0	Any	—	
Neutral mass spectrometer	67 to 10	Any	12	
Solar radiometer	67 to 0	Any	—	
Cloud particle analyzer	67 to 0	Any	1	Outer window jettisoned at 40 km
IR flux radiometer	67 to 0	Any	—	Inlet cover removed and helium gas on at 67 km
Gas chromatograph	67 to 0	Any	2	
Hygrometer	67 to 44	Any	—	Not required to operate below 44 km, but will be left on
Wind-altitude radar	40 to 0	>5	—	Requires spin signal related to Venus or other coordinates



TABLE 3-33. LARGE PROBE TERMINAL DESCENT EXPERIMENT  
DATA SAMPLING REQUIREMENTS

Instrument	Measurements			Minimum Sampling Interval	
	Description	Analog or Digital	Size, bits	Altitude, m	Time, sec
Temperature	Atmosphere temperature	A	10	200	NA
	Thermistor	A	7	NA	140
Pressure	Atmosphere pressure	A	10	200	NA
	Thermistor	A	7	NA	140
Acceleration (See Note a)	Turbulence	A	7	100	NA
	Axial	A	10	NA	20
	Axial backup	A	10	NA	20
	Lateral	A	10	NA	40
	Lateral	A	10	NA	40
	Thermistor	A	7	NA	140
Hygrometer	Humidity	A	10	500 (b)	NA
	Range	A	1	500 (b)	NA
	Housekeeping	A	10	1 per every 10 humidity measurements	NA
Particle size analyzer	Science and housekeeping	D	240	200	NA
Solar radiometer	Science and housekeeping	D	240 (c) 72 (d)	750	NA
IR flux	Science and housekeeping	D	100	750	NA
Wind-altitude radar	Science	D	37	NA	20
	Voltage	A	7	NA	60
	Temperature	A	7	NA	60

(a) A total of 1000 bits of data recorded during entry are to be read out during the probe descent.

(b) No measurements required below 44 km.

(c) 66 km to 44 km.

(d) 44 km to the surface.

TABLE 3-34. LARGE PROBE SCIENCE DATA RETURN CAPABILITY

Instrument	Measurement	Data Rate, bps			
		Required Above 20 km	Actual Above 20 km	Required Below 20 km	Actual Below 20 km
Temperature gauge	Atm. temperature	1.77	2.50	0.84	1.25
	Thermistor	0.05	0.05	0.05	0.05
Pressure gauge	Atm. pressure	1.77	2.50	0.84	1.25
	Thermistor	0.05	0.05	0.05	0.05
Accelerometer	Turbulence	2.47	2.63	1.17	1.31
	Axial	0.50	0.62	0.50	0.62
	Axial backup	0.50	0.62	0.50	0.62
	Lateral	0.25	0.31	0.25	0.31
	Lateral	0.25	0.31	0.25	0.31
	Thermistor	0.05	0.05	0.05	0.05
Hygrometer	Humidity	0.71	1.25	0.00	0.62
	Range	0.07	0.08	0.03	0.08
	Housekeeping	0.07	0.08	0.03	0.08
Particle size analyzer	Science and housekeeping	42.40	47.50	20.08	20.62
Solar radiometer	Science and housekeeping	11.31	12.50	1.61	1.88
IR flux radiometer	Science and housekeeping	1.70	5.00	2.23	2.50
Wind-altitude radar	Science	1.85	2.50	1.85	1.88
	Voltage	0.12	0.11	0.12	0.11
	Temperature	0.12	0.11	0.12	0.11
Playback	Acceleration	0.70	0.70	0.00	0.70
Mass spectrometer	Science and housekeeping	55.05	60.00	29.46	30.00
Gas chromatograph	Science and housekeeping	11.00	12.50	11.00	11.25
Science total		135.76	151.97	71.36	75.65
Eng., Sync. and ID, Spares, Analog Overhead		—	8.03	—	4.35
Total		—	160.00	—	80.00

The temperature, acceleration, and pressure measurements are the only ones requiring a 10 bit encoding accuracy, thereby establishing word size for the telemetry system.

The mass, volume, and power allocated to the large probe for the science payload are 31.3 kg (69.5 lb), 34,300 cm<sup>3</sup> (2096 in<sup>3</sup>), and 106.3W. This includes a 15 percent increase in mass and volume and a 20 percent increase in power over the specified nominal values. These numbers represent the upper limits of the tolerances placed on the nominal values by NASA/ARC. (In thermal design studies the negative mass tolerance was assumed.)

Layout of the science instruments is shown in Figure 3-37. The design of the probe has been suitably configured to accommodate not only the physical parameters of the various science instruments, along with the pointing direction and fields-of-view, but also to allow reasonable access for replacement and servicing. The majority of the instruments have been accommodated in the middle bay, which affords easiest access should it be required. Mechanical integration details for the individual instruments are summarized in Table 3-35.

The Thor/Delta large probe nominal payload was presented in Table 3-2. Figure 3-38 shows the layout of the science instruments in the Thor/Delta baseline design, in relation to other equipment. Science location and fields of view are displayed separately in Figure 3-39. The nephelometer and aureole detector shown here do not appear in the Atlas/Centaur payload; on the other hand neither the gas chromatograph nor the wind altitude radar were included in the Thor/Delta design at mid-term.

Accommodation of each of the Atlas/Centaur science instruments is discussed in more detail in the following paragraphs. Much of the discussion also applies to the Thor/Delta case.

#### Temperature Gauge

The temperature sensor is required to be mounted outside the boundary layer at a position of maximum air flow. It has been located approximately 60 deg from the probe descent axis in the forward hemisphere, protruding 5.2 cm (2 in.) beyond the aerodynamic cover with consideration given to preventing physical interference when the aeroshell is jettisoned.

The instrument is turned on 15 minutes prior to entry for warmup and operates continuously to the surface. The temperature measuring system provides an analog output signal requiring 10 bit encoding accuracy.

#### Pressure Gauge

The basic requirement on the pressure sensor is to locate the pressure inlet hole within 30 deg of the probe stagnation point while minimizing the line length to the internal sensor. Shelf and pressure vessel wall locations for the sensor unit were studied; the wall mounted sensor provides significantly reduced line lengths for the system and has been chosen for the baseline. The pressure inlet and connecting tube to the pressure sensor is sized at 6.3 mm (0.25 in.) diameter, and the inlet is located 30 deg from the stagnation point.

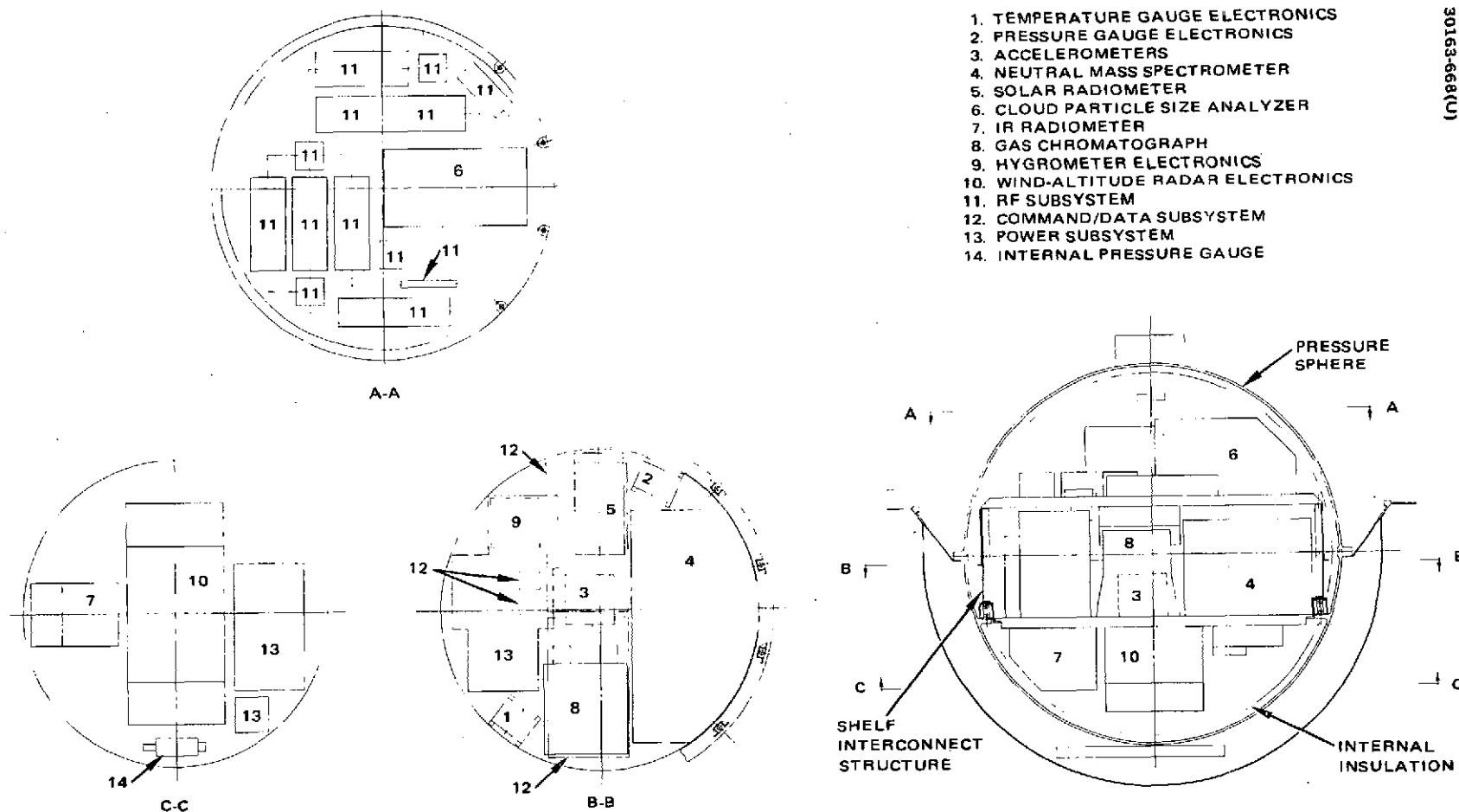
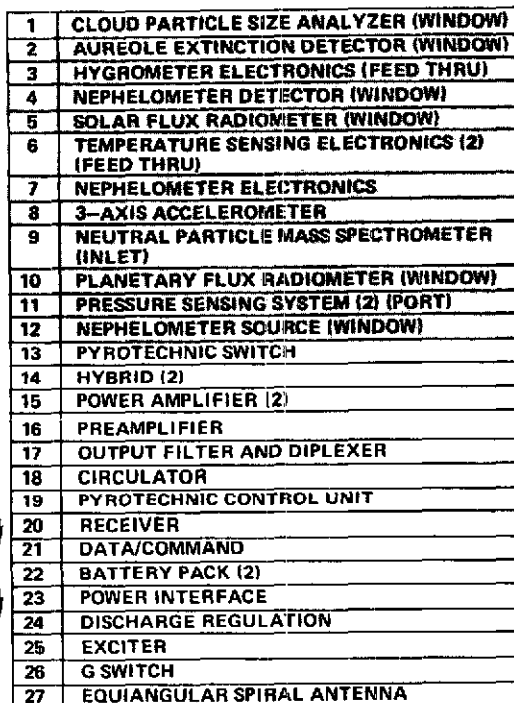


FIGURE 3-37. ATLAS/CENTAUR LARGE PROBE PRESSURE VESSEL

TABLE 3-35. MECHANICAL INTEGRATION DETAILS  
FOR LARGE PROBE INSTRUMENTS

Instrument	Ports		Windows		Sensor Location	Size, cm (in.)	
	Number	Size cm (in.)	Number	Size cm (in.)		Electronics	Sensor
Temperature Gauge	—	—	—	—	Lower hemisphere external sensor	5.08 x 5.08 x 2.54 ( 2.00 x 2.00 x 1.00 )	1.9 L x 0.64 dia ( .75 L x 0.25 dia )
Pressure Gauge	1	0.64 dia (0.25)	—	—	Close to stagnation point	2.54 x 5.08 x 7.62 ( 1.00 x 2.00 x 3.00 )	
Accelerometer	—	—	—	—	c. g.	7.62 x 8.89 x 8.89 ( 3.00 x 3.50 x 3.50 )	
Neutral mass spectrometer	1	7.62 dia (3.00)	—	—	Lower hemisphere 45 deg to spin axis	25.4 x 25.4 x 15.24 (10.0 x 10.0 x 6.0 )	
Solar radiometer	1	1.27 dia (0.5 )	—	—	Views $\pm 45$ deg from normal to spin axis	10.16 x 11.43 x 13.34 ( 4.00 x 4.50 x 5.25 )	1.27 x 2.54L light pipes ( 0.5 x 1.0 )
Cloud particle analyzer	—	—	1	1.5 (0.6)	90 deg to spin axis external mirror mount	25.4L x 12.7 dia (10.0L x 5.0 dia)	1.27 mirror on 15.24 strut ( 0.5 ) (6.0)
IR flux radiometer	—	—	1	1.27 (0.5 )	Downward viewing	12.7 x 12.7 x 10.16 ( 5.0 x 5.0 x 4.0 )	
Gas chromatograph	1	0.64 dia (0.25)	—	—	Lower hemisphere 45 deg to spin axis	16.51 x 16.51 x 15.24 ( 6.5 x 6.5 x 6.0 )	
Hygrometer	—	—	—	—	External sensor lower hemisphere parallel to spin	2.54 x 6.34 x 12.70 ( 1.00 x 2.50 x 5.00 )	1.27 dia x 17.78 L ( 0.50 dia x 7.00 L )
Wind-altitude radar	2	2.54 x 1.27 (1.00 x 0.50)	—	—	External antenna at nose of probe views downward	30.48 x 30.48 x 7.62 (12.00 x 12.00 x 3.00)	25.40 x 25.40 x 1.91 (10.00 x 10.00 x 0.75)



\*TRANSPONDER INCLUDED IN RF SUBSYSTEM

1 PRESSURE VESSEL MODULE/  
DECELERATION MODULE  
ADAPTER

MASS  
SPECTROMETER  
INLET

FIGURE 3-38. THOR/DELTA LARGE PROBE PRESSURE VESSEL MODULE

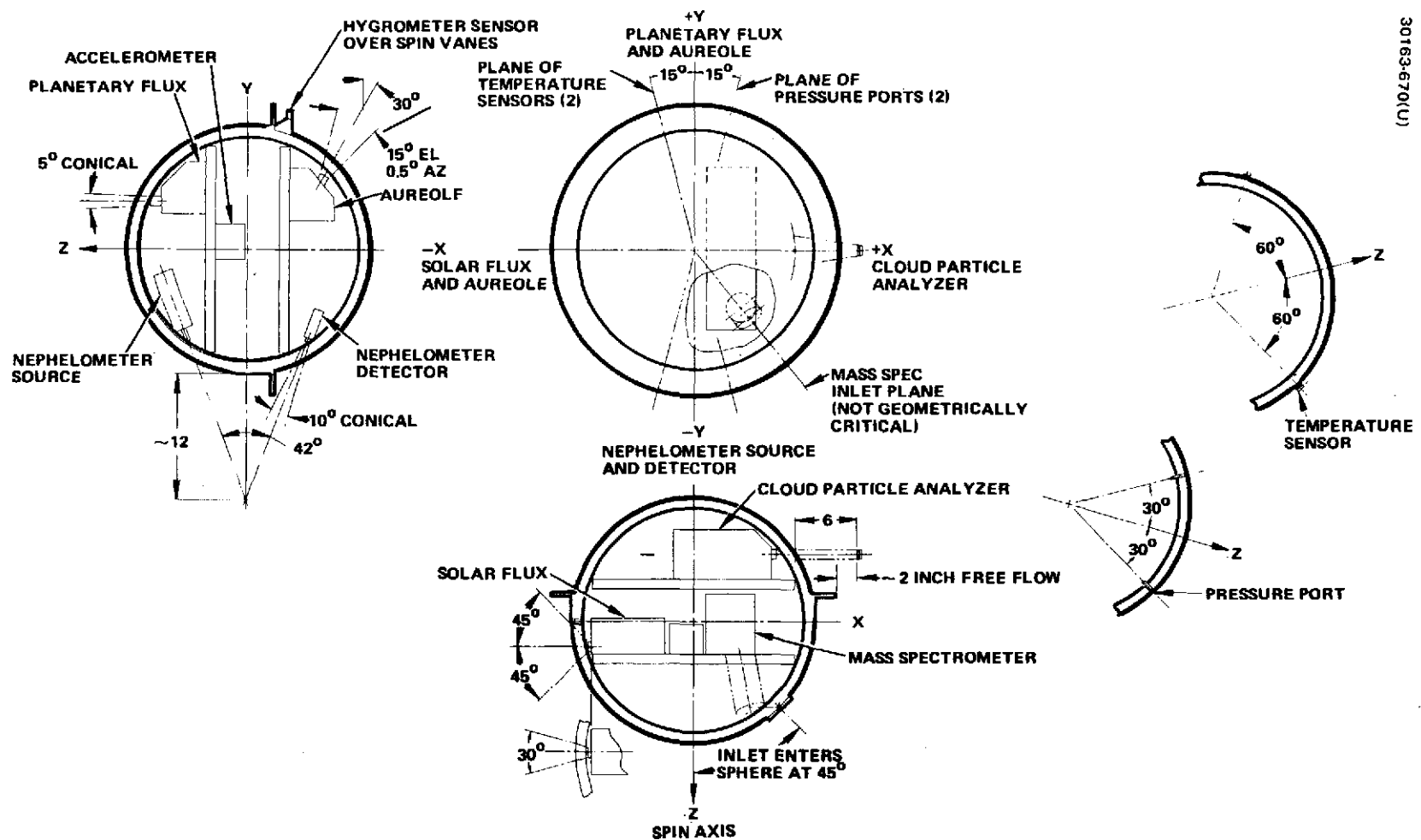


FIGURE 3-39. THOR/DELTA LARGE PROBE SCIENCE LOCATION AND FIELD OF VIEW

TABLE 3-36. LARGE PROBE ACCELEROMETER SAMPLING RATE  
(WORDS PER SECOND)

Phase	Measurement				
	Primary Axial	Backup Axial	Lateral No. 1	Lateral No. 2	Turbulence
Calibration	1.0	1.0	1.0	1.0	0
Entry	8.0	0	0	0	0
Blackout	2.5	2.5	2.5	2.5	0
Post-Blackout	1.0	1.0	1.0	1.0	1/7
Descent	0.05	0.05	0.025	0.025	1/7
Seismic	6.0	0	0	0	0
Word Size (bits)	10	10	10	10	7



The instrument is turned on 15 minutes prior to entry for warmup and operates continuously to the surface. This instrument also requires 10 bit encoding.

### Accelerometer

The accelerometer is required to be located on the probe spin axis and at the c. g. It is a three-axis device with a fourth single axis unit providing a redundant measurement of axial acceleration. All four accelerometers along with the electronics are contained in one unit within 2.5 mm of the c. g. The axial sensing is aligned within 0.017 deg of the probe axis.

The accelerometer has two modes of operation: direct readout and storage (during entry blackout). There are six phases of operation: 1) calibration - a 5 minute period of operation just after probe separation from the bus; 2) entry - defined as extending from an acceleration level of approximately  $4 \times 10^{-4}$  g until blackout; 3) blackout - a period of approximately 10 seconds starting at about 0.5 g; 4) post-blackout - the period from the end of blackout until parachute deployment; 5) descent - from parachute deployment until impact; 6) seismic - post impact. The required data rate for each phase is given in Table 3-36. In addition to the accelerometer readings, turbulence measurements are made by the accelerometer system during the post-blackout and descent phases.

The instrument is turned on 15 minutes prior to entry and operates continuously to the surface, where it remains on to make seismic measurements. Except for the turbulence measurements, 10 bit encoding is required.

### Neutral Mass Spectrometer

The mass spectrometer inlet system must be located outside the boundary layer at a location between 30 and 60 deg from the stagnation point and must be hermetically sealed to the pressure vessel where it penetrates. For purposes of design a 7.6 cm (3 in.) diameter inlet system was assumed, although this is felt to be quite conservative.

The instrument is positioned in the middle bay as near to the pressure vessel wall as the instrument shape will allow. The inlet system is 45 deg from the probe axis and protrudes just beyond the aerodynamic fairing to ensure that boundary layer conditions are not an influencing factor. Figure 3-13 shows the inlet system design.

The mass spectrometer is turned on at 70 km and has special sampling requirements. A minimum of 80,000 bits of data will be generated between 66 and 44 km. This data is read out at 60 bps by the probe data system. The number of bits per complete sample will vary due to the adaptive measuring technique within the instrument; this is accounted for by the instrument data processing system. From 44 km to the surface a minimum of 88,000 bits are generated. This data is read out at 30 bps because of the longer time available. A few seconds after impact the instrument is turned off.

Allowance has been made for 12 squib actuated events. Two squibs are required for removal of the inlet cover at 67 km altitude, and the remaining 10 are for inlet valve open and close events. The probe system will provide 12 squib drivers. It is assumed that squibs will be provided with the instrument.

This instrument presents some of the more difficult accommodation problems for the large probe primarily because of its size and required location. Details must eventually be worked out with the selected instrument(s), including sequencing, data processing, pyrotechnic, and physical integration.

#### Solar Radiometer

The solar radiometer selected for integration evaluation purposes is required to have an unobstructed view 30 deg wide and  $\pm 45$  deg up and down with respect to the local horizontal. It is positioned in the middle bay and looks out in the lower hemisphere just below the main pressure sealing flange. The pressure vessel opening is approximately 1.3 cm (0.5 in.) in diameter, to allow for the projection of a series of angled light pipes providing  $\pm 45$  deg coverage.

The instrument is turned on at 70 km and operates to the surface. The required sample size is 240 bits above 44 km and 72 bits below 44 km, with a sampling interval of 750 meters. The implemented data rate more than meets this requirement as shown in Table 3-34.

#### Cloud Particle Size Analyzer

The cloud particle size analyzer utilizes an externally mounted mirror as part of its optical subsystem. This mirror must maintain its position and alignment to within  $\pm 1$  mr after exposure to the 610 g acceleration load of Venus entry and to the Venus surface temperature and pressure. Two configurations were considered: 1) mounting the mirror support structure to the pressure vessel wall and 2) keeping the mirror mount integral with the instrument, as shown in Figure 3-14. The integral mount was selected to meet the alignment requirements.

This instrument has been located in the upper equipment bay. The mirror is mounted on 15.2 cm (6 in.) struts and extends horizontally into the airstream aft of the main pressure flange. A 1.5 cm (0.6 in.) diameter window is provided in the pressure vessel for the transmitted and reflected light beam. To minimize possible window contamination through condensation or deposit of particulate matter, a transparent heated cover is provided. This is jettisoned at 40 km, exposing a clean inner window.

The instrument is turned on at 70 km and operates to the surface. With a sample size of 240 bits and a 200 meter sampling interval, this instrument has the highest data rate requirement of any science instrument except the mass spectrometer. It is thus one of the more difficult instruments to accommodate from both a mechanical integration aspect and a data handling aspect.

### Infrared Flux Radiometer

The IR flux detector requires a downward looking window with a 5 deg field of view. The instrument is located in the lower equipment bay. With the wind/altitude radar occupying a large area at the nose of the probe, the IR window has been located about 45 deg from the probe axis, with a front surface mirror directing the field of view downward, as shown in Figure 3-40. To maintain the aerodynamic contour of the probe, the mirror is "buried" between the aerodynamic fairing and the pressure vessel wall. The protruding portion of the mirror and its support structure are covered by a streamlined fairing. The pressure sealing window in the pressure vessel is 1.3 cm (0.5 in.) in diameter. It is not heated as window contamination is not a serious problem for this instrument.

A heater for the IR flux detector is turned on 2 days prior to entry to provide the reference source needed in the instrument for proper operation. The instrument is turned on at 70 km and operates to the surface.

### Gas Chromatograph

The gas chromatograph inlet system must be located in the forward hemisphere of the probe. The gas chromatograph is located in the middle equipment bay and is connected to an opening in the aerodynamic fairing by a 0.64 cm (0.25 in.) tube. The inlet is located about 45 deg to the descent axis. A probe descent time of at least 60 minutes is required to analyze and readout the data for three gas samples.

The instrument is turned on at 70 km and makes one measurement cycle every 20 minutes regardless of altitude interval. During the first 10 minutes, the instrument performs the gas analysis. No data is available for readout by the probe during this period. During the last 10 minutes of the 20 minute cycle, the instrument provides the science data in digital form to be readout during this period. A total of 13,200 bits will be read out. The readout can be stretched into the next 10 minute measuring period if desired. This would extend the last cycle another 10 minutes.

Approximately 4000 cc's of He will be vented into the pressure vessel during the operation of this instrument. This will not cause any problems.

### Hygrometer

The hygrometer sensor requires free stream flow to the sensor tube. The 17.8 cm (7 in.) long sensor and flow control tube is mounted on the inside of the aerodynamic fairing (between the fairing and the pressure vessel). A scoop in the fairing surface directs free stream air to the sensor inlet while bleeding off the low energy boundary layer.

The hygrometer is turned on at 70 km and will remain on to the surface, although no measurements are expected below 44 km, where the temperature is approximately 100° C.

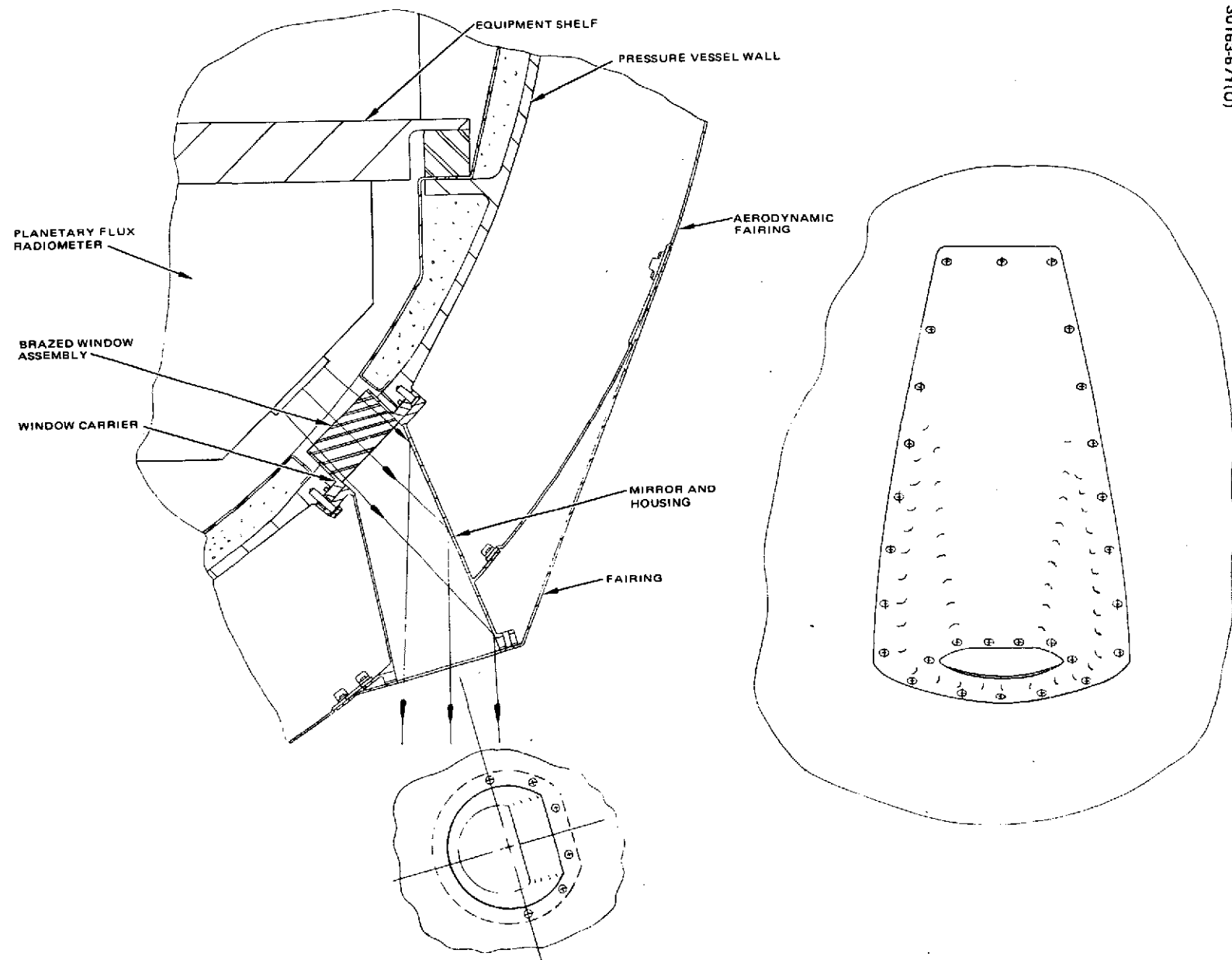


FIGURE 3-40. PLANETARY FLUX RADIOMETER WINDOW

### Wind Drift/Altitude Radar

Basic requirements for the wind drift/altitude radar are 1) the antenna must be located so as to provide an unobstructed downward view from parallel to the spin axis to 10 deg off axis plus half the 8 deg beamwidth, or 14 deg total; 2) the coaxial cables leading from the antenna to the electronics must be as short as possible and of equal length; and 3) the antenna installation must not affect the aerodynamic stability of the probe.

The instrument is located in the lower equipment bay, with a 25.4 cm (10 in.) by 25.4 cm (10 in.) planar array antenna positioned at the forward end of the probe outside the pressure vessel, perpendicular to the probe axis, as shown in Figure 3-41. A ceramic foam radome covers the antenna and provides a clean aerodynamic surface. Two coaxial feeds connect the antenna to the electronics through sealed ports in the pressure vessel. This could be reduced to one coax penetration if the power divider is located at the antenna.

The radar is turned on at 40 km and operates to the surface. Probe spin is required and a rate of >5 rpm is preferred. Four samples are taken per spin cycle. A higher spin rate, up to 40 rpm, can easily be accommodated by the instrument, but low spin rates (<2 rpm) are difficult because of extremely long averaging times.

The instrument will require a spin rate reference signal for proper operation. This is not currently included in the probe baseline design. Some possibilities are rate gyros, a radially displaced accelerometer, or possibly using the nonuniformity of the antenna pattern. It would also appear that directional data with regard to Venus north, south, east or west would also be required. NASA/ARC has indicated that they are considering techniques to provide this data.

### Small Probe

The Atlas/Centaur small probe nominal payload was presented in Table 3-12. The descent trajectory is shown in Figure 3-42. The small probe does not utilize a parachute. As the probe slows down, the data rate is reduced at 44 km, and again at 20 km to optimize the data return. Operating characteristics for the science instruments are given in Table 3-37. Currently none of the small probe instruments require spin. Science data sampling requirements are shown in Table 3-38, and data rate allocations in Table 3-39. The NASA/ARC required data rates are met or exceeded in all cases. All science is turned on 15 minutes prior to entry, and remains on to impact, where everything is turned off except the accelerometer, temperature and pressure to maximize the chances of receiving this primary data on the surface should the probe survive and orientation of the antenna be adequate to provide sufficient gain.

The mass, volume, and power allocated to the small probe payload are 2.5 kg (5.6 lb), 1416 cm<sup>3</sup> (86.2 in.<sup>3</sup>) and 5.1W. This includes a 15 percent increase in mass and volume and a 20 percent increase in power over the nominal payload values. These numbers represent the upper limits on the tolerances placed on the nominal values. (For thermal analysis the negative mass tolerance was considered for design purposes.)

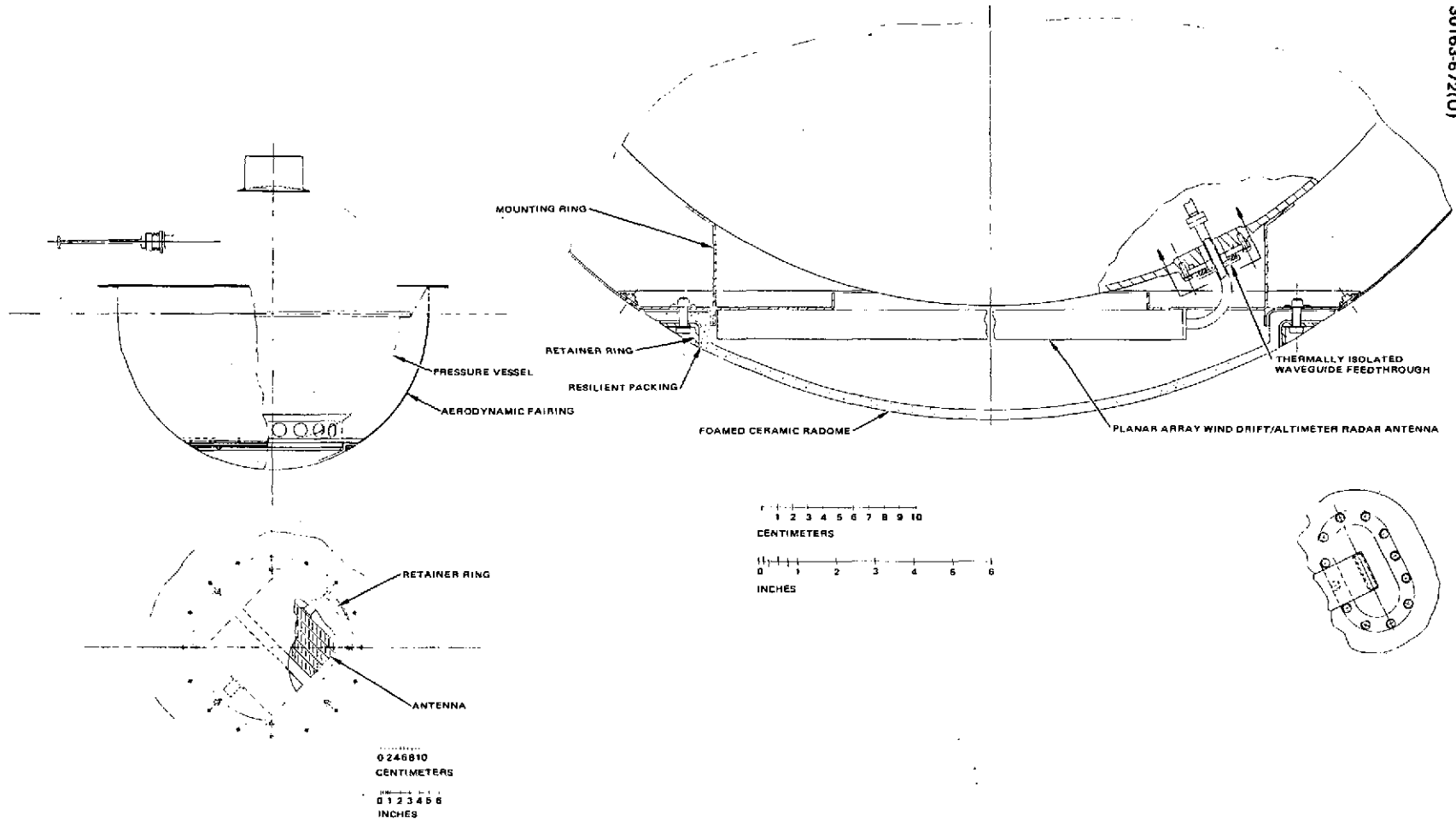


FIGURE 3-41. WIND/DRIFT ALTIMETER RADAR ANTENNA INSTALLATION

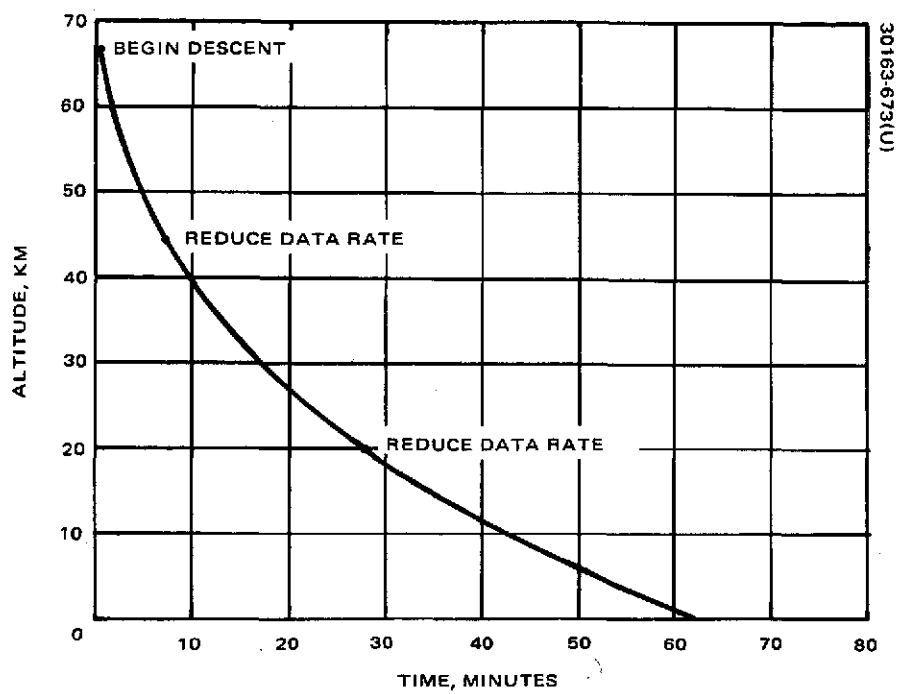


FIGURE 3-42. SMALL PROBE DESCENT PROFILE

TABLE 3-37. OPERATING DETAILS FOR SMALL PROBE INSTRUMENTS

Instrument	Operating Altitude, km	Squib Activated Events	Remarks
Temperature gauge	67 to 0	1	Sensor deployed
Pressure gauge	67 to 0	1	Sensor deployed
Accelerometer	150 to 0	—	Data stored during entry
IR flux detector	67 to 0	1	Sensor deployed
Stable oscillator	150 to 0	—	Heater turned on 45 minutes prior to entry
Nephelometer	67 to 0	1	Cover removed



TABLE 3-38. SMALL PROBE TERMINAL DESCENT EXPERIMENT  
DATA SAMPLING REQUIREMENTS

Instrument	Measurements			Minimum Sampling Interval	
	Description	Analog or Digital	Size, bits	Altitude, m	Time, sec
Temperature	Atmosphere temperature	A	10	200	NA
	Thermistor	A	7	NA	140
Pressure	Atmosphere pressure	A	10	200	NA
	Thermistor	A	7	NA	140
Accelerometer (See Note a)	Turbulence	A	7	100	NA
	Axial	A	10	NA	20
	Thermistor	A	7	NA	140
Nephelometer	Science	D	43	200	NA
	Calibration	D	10	NA	900
Flux radiometer	Net Flux	D	8	NA	30
	Detector temperature	D	8	NA	60
	Window temperature	D	8	NA	60

- (a) A total of 250 bits of data recorded during entry are to be read out during the probe descent.
- (b) The experiment data sampling requirements shown above are based on the following assumptions:
- 1) The altitude interval from 66 km to the surface is selected as the reference measurement regime. The minimum acceptable number of measurements, per unit distance (minimum sampling interval), is specified for each instrument for the altitude interval.
  - 2) The number of measurements sampled above 66 km will be dictated by the sampling rate selected to satisfy the requirements for the reference altitude interval, per item 1 above.
  - 3) Certain measurements are to be sampled on a time interval basis which is not dependent on the altitude interval traveled.

TABLE 3-39. SMALL PROBE SCIENCE DATA RETURN

Instrument	Measurement	Data Rates, bps					
		Required Above 44 km	Actual Above 44 km	Required 44-20 km	Actual 44-20 km	Required Below 20 km	Actual Below 20 km
Temperature gauge	Atm. temperature	6.52	6.56	1.61	3.28	0.66	0.78
	Thermistor	0.05	0.08	0.05	0.04	0.05	0.11
Pressure gauge	Atm. pressure	6.52	6.56	1.61	3.28	0.66	0.78
	Thermistor	0.05	0.08	0.05	0.04	0.05	0.11
Accelerometer	Turbulence	9.13	9.18	2.26	4.59	0.92	1.09
	Axial	0.50	0.94	0.50	0.47	0.50	0.78
	Thermistor	0.05	0.08	0.05	0.04	0.05	0.11
Nephelometer	Science	28.04	28.12	6.93	14.06	2.83	3.28
	Calibration	0.01	0.06	0.01	0.04	0.01	0.08
IR flux detector	Net flux	0.27	0.52	0.27	0.26	0.27	0.78
	Detector temperature	0.13	0.18	0.13	0.09	0.13	0.23
	Window temperature	0.13	0.18	0.13	0.09	0.13	0.23
Playback	Acceleration	*	0.94	*	0.47	0.00	0.00
Science total		51.40	53.48	13.60	26.75	6.26	8.28
Eng., Sync and ID, Spares, Analog Overhead		—	6.52	—	3.25	—	1.72
Total		—	60.00	—	30.00	—	10.00

\*Required total data playback = 250 bits, implemented playback = 1160 bits.

Layout of the science instruments is shown in Figure 3-43. Unlike the large probe, the heat shield of the small probe is not ejected, but stays with the pressure vessel throughout the probe descent. The shield covers the lowest section of the vessel and extends to a point just above the mid-latitude. Because of this, the instruments have not been confined to the middle bay, due to the problems of penetrating the shield for external viewing. An exception to this is the pressure instrument which requires an inlet at the stagnation point and therefore access through the heat shield. Other than this, those instruments that are required to view or sample the Venusian atmosphere are located in the upper bay. Mechanical integration details for individual instruments are summarized in Table 3-40.

The Thor/Delta small probe nominal payload was presented in Table 3-8. Figure 3-44 shows the layout of the science instruments in the Thor/Delta baseline design, in relation to other equipment. The science location and field of view are displayed separately in Figure 3-45. The magnetometer shown here has been deleted in the Atlas/Centaur payload, and an IR flux detector has been added.

Accommodation of each of the Atlas/Centaur science instruments is discussed in more detail in the following paragraphs. Much of the discussion also applies to the Thor/Delta case.

#### Temperature Gauge

The temperature sensor must be extended outside the heat shield to ensure proper sampling of the Venusian atmosphere. Unless properly protected it would be destroyed during the high temperatures generated during entry. To provide this protection, a swing-out deployment mechanism is utilized, with the sensor positioned on the aft step of the heat shield. It is stowed under and protected by an ablative covered pocket. After entry, a squib activated device permits the sensor arm to swing out clear of the heat shield step as seen in Figure 3-46.

The temperature gauge electronics unit is positioned in the upper bay.

#### Pressure Gauge

The pressure sensor is required to measure pressure at the probe stagnation point. This requires a penetration of the probe aeroshell and ablator for the inlet. A jettisonable teflon plug, removed by a squib-activated spring driven piston was selected as a baseline to cover the inlet as shown in Figure 3-47. This technique prevents blockage of the pressure inlet tube by the ablative heat shield material during entry.

#### Accelerometer

The accelerometer is required to be located on the probe spin axis at the c.g. point. It is a single axis device. The sensor axis is aligned within 0.017 deg of the probe axis. The unit is mounted within 2.5 mm of the probe c.g. location.

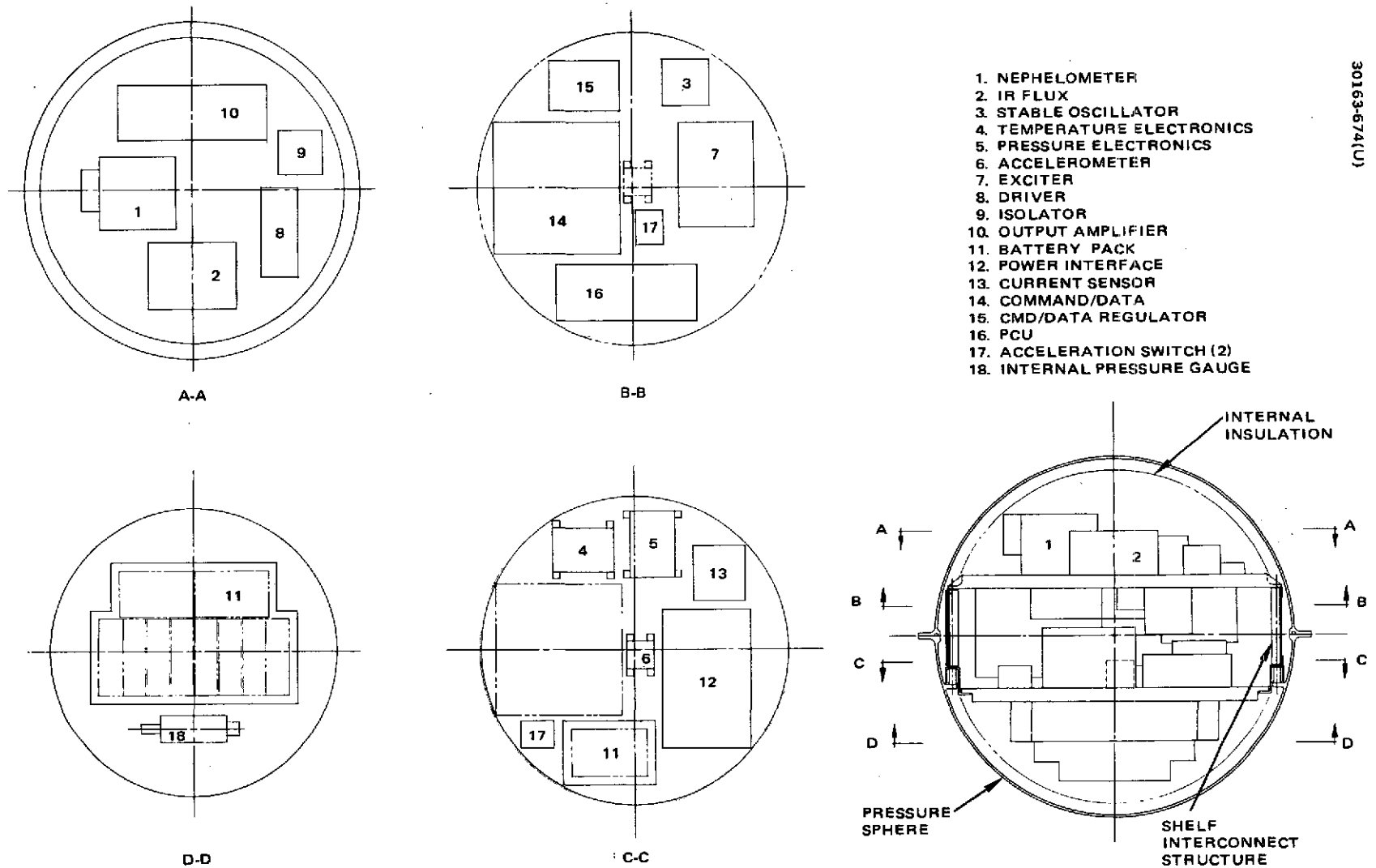


FIGURE 3-43. ATLAS/CENTAUR SMALL PROBE PRESSURE VESSEL

TABLE 3-40. MECHANICAL INTEGRATION DETAILS  
FOR SMALL PROBE INSTRUMENTS

Instrument	Ports		Windows		Sensor Location	Size, cm (in. )	
	Number	Size cm (in. )	Number	Size cm (in. )		Electronics	Sensor
Temperature Gauge	—	—	—	—	In maximum flow region, deployable arm	5.08 x 5.08 x 2.54 (2.0 x 2.0 x 1.0 )	1.91 x 0.64 dia (0.75 x 0.25 dia)
Pressure Gauge	1	0.64 dia (0.25)	—	—	At stagnation point	2.54 x 5.08 x 7.62 (1.0 x 2.0 x 3.0 )	
Accelerometer	—	—	—	—	At c. g.	3.18 x 3.18 x 3.18 (1.25 x 1.25 x 1.25)	
IR flux detector	—	—	—	—	Looks up and down, two fixed sensors on deployable arm	5.08 x 5.08 x 12.70 (2.0 x 2.0 x 5.0 )	1.91 x 0.64 dia (0.75 x 0.25 dia)
Stable oscillator	—	—	—	—	—	Sphere 131 cm <sup>3</sup> (8 in <sup>3</sup> )	
Nephelometer	—	—	1	3.8 dia (1.5)	Looks <u>⊥</u> to spin	10.16 x 10.16 x 5.08 (4.0 x 4.0 x 2.0)	

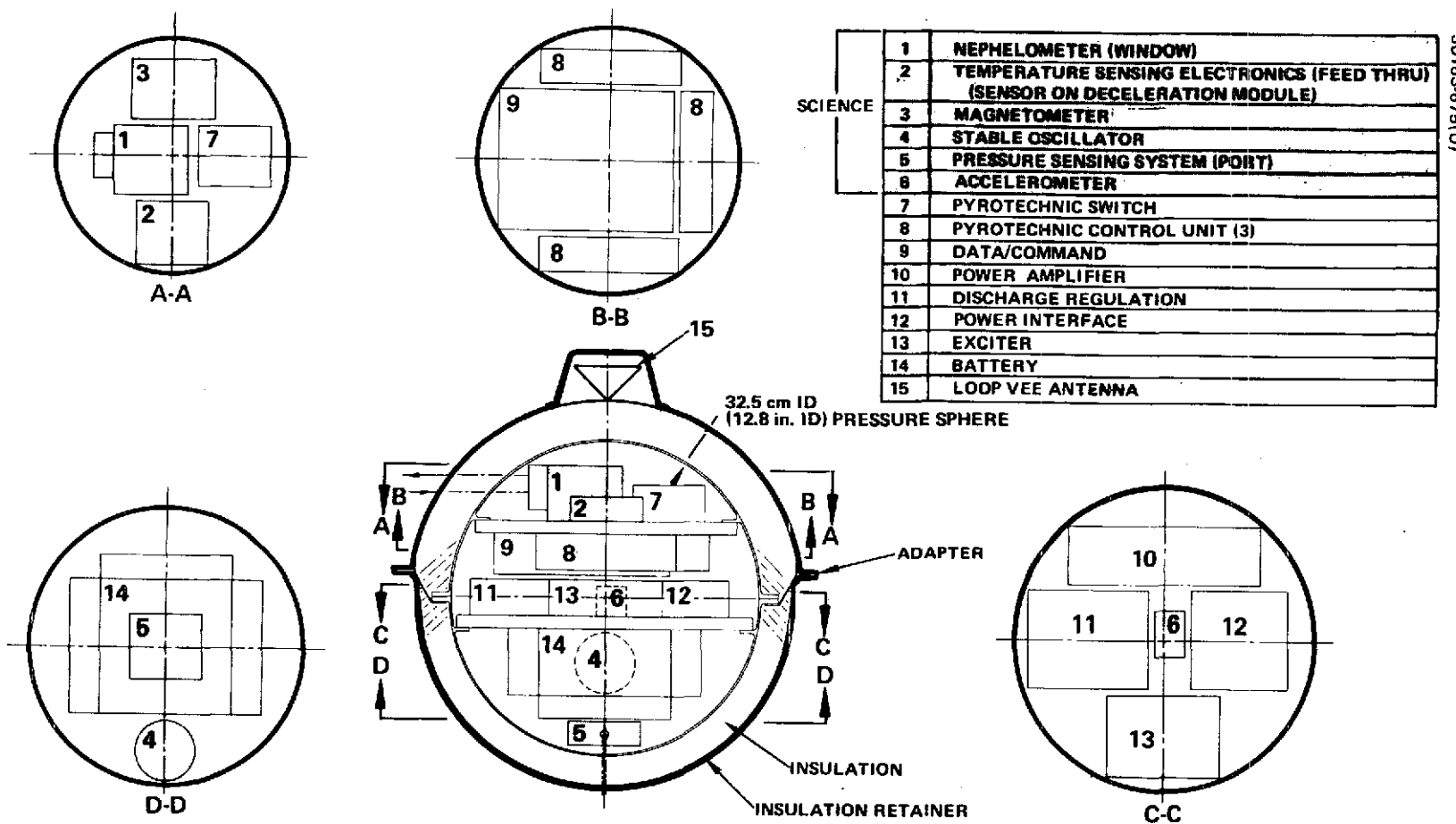
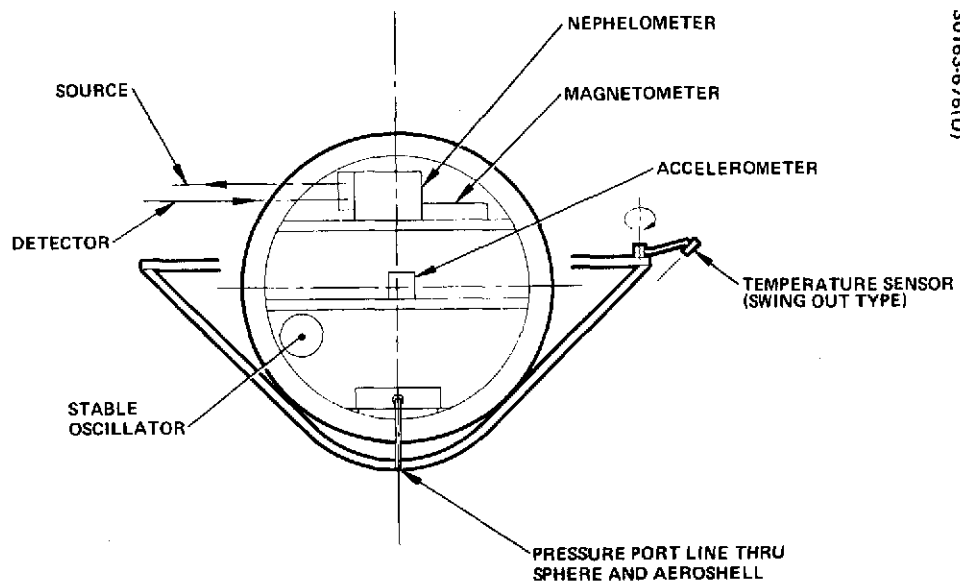


FIGURE 3-44. THOR/DELTA SMALL PROBE PRESSURE VESSEL MODULE



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FIGURE 3-45. THOR/DELTA SMALL PROBE SCIENCE LOCATION AND FIELD OF VIEW

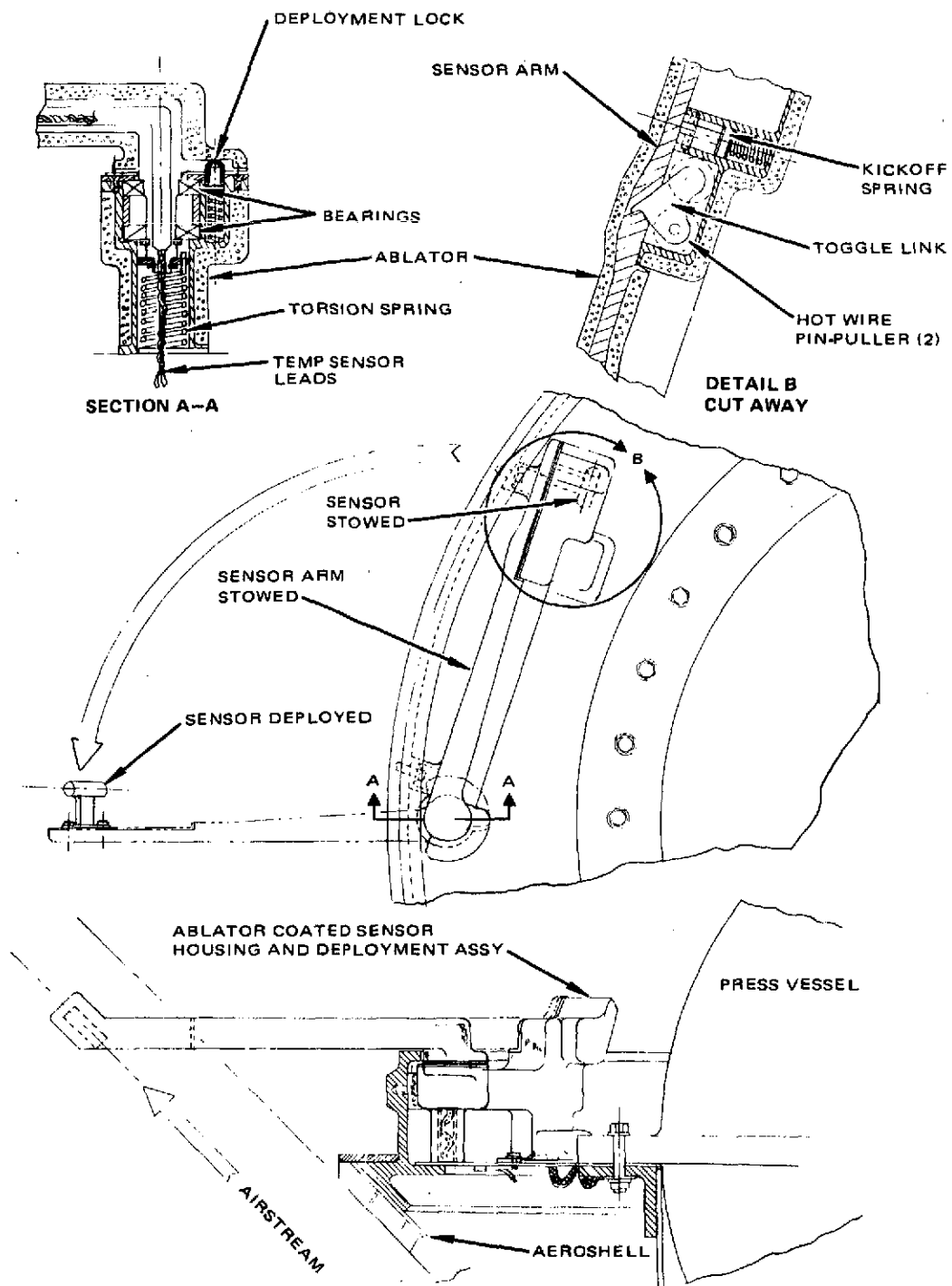
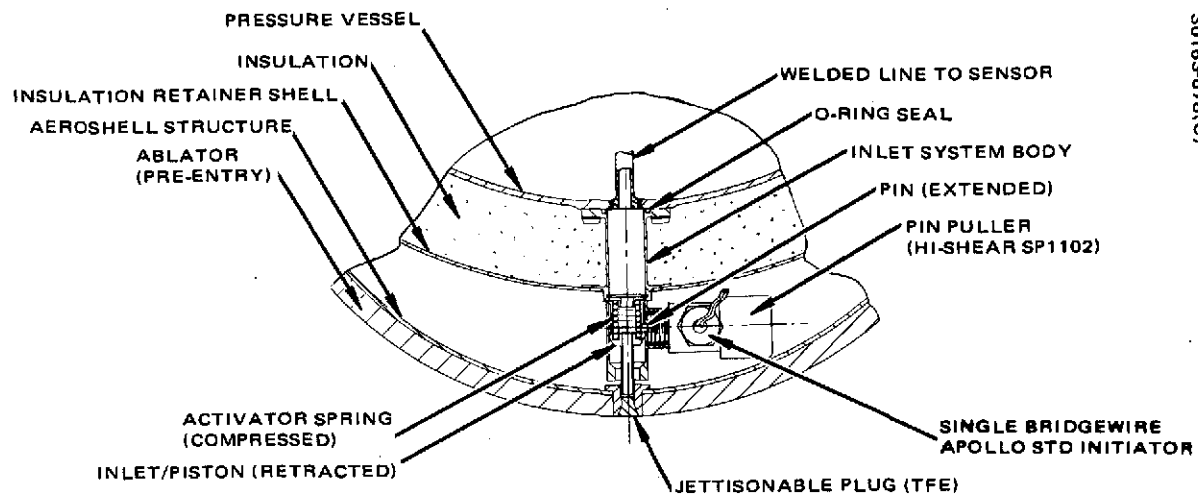
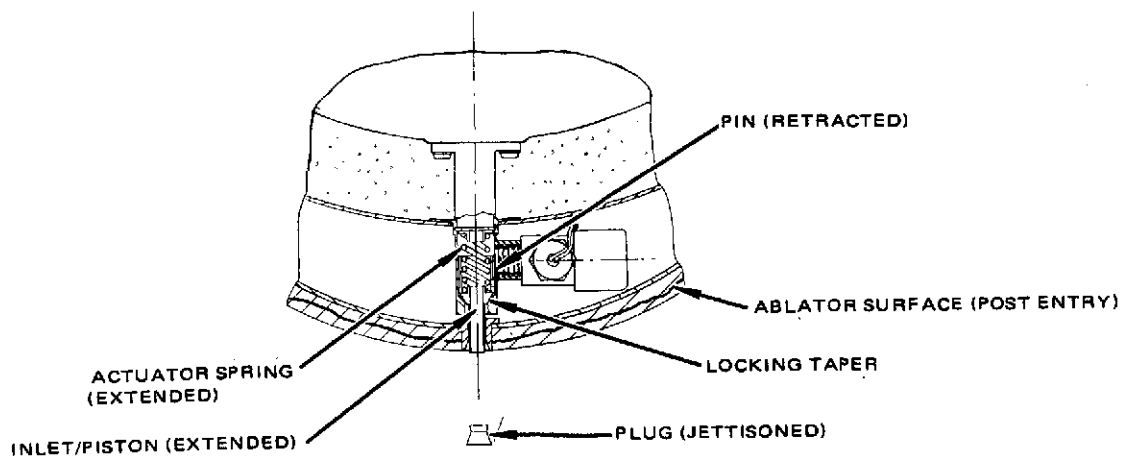


FIGURE 3-46. SWING ARM DEPLOYABLE TEMPERATURE SENSOR





a) INLET RETRACTED



b) INLET DEPLOYED

FIGURE 3-47. JETTISONABLE PLUG INLET SYSTEM

TABLE 3-41. SMALL PROBE ACCELEROMETER SAMPLING RATE  
(Words per Second)

Phase	Measurement	
	Primary Axial	Turbulence
Calibration	1.	0.
Entry	1.	0.
Blackout	1.	0.
Descent	0.05	1/14
Seismic	1.	0.
Word Size (bits)	10	7

As in the case of the large probe accelerometer, data is stored during entry blackout. There are five phases of operation: calibration, entry, blackout, descent, and seismic. The data rate for each phase is given in Table 3-41.

#### IR Flux Detector

The IR flux detector requires a deployable boom with two detectors, one looking up and the other down. A similar deployment mechanism to that of the temperature probe will be employed, with the sensor arm stowed behind the aft step during the entry phase. At an altitude of 67 km, it is deployed 90 deg to the descent axis by a squib-activated device. The electronics unit is located in the upper bay.

#### Stable Oscillator

The stable oscillator for the DLBI/doppler experiment will be provided by Hughes. There are no special accommodation requirements. The frequency stability of  $10^9$  is discussed in the communication section. It is positioned in the middle bay, attached to the underside of the top shelf.

A heater is required to meet the frequency stability requirements. It is turned on 45 minutes prior to entry by a timer in order to ensure temperature stability during descent.

#### Nephelometer

The nephelometer requires a window to view the atmosphere and determine the cloud layers. The window will require protection during entry. This instrument is positioned in the upper bay looking 90 deg to the probe descent axis. A 3.8 cm (1.5 in.) sapphire window is provided in the pressure vessel, allowing for both the source beam and the reflected beam from the cloud illumination as shown in Figure 3-48. The window is heated to minimize condensates. A jettisonable protective cover is provided to enable the window to withstand the entry heating condition. The protective cover is jettisoned after entry, exposing the clean window surface. No further techniques are used to keep the window free of contaminants the rest of the way to the surface. Figure 3-49 shows the cover ejection technique. An inner window is provided behind the sapphire window to minimize heat transfer from the heated window into the probe interior.

#### Probe Bus

The Atlas/Centaur probe bus nominal payload was presented in Table 3-17. The entry profile is shown in Figure 3-50 from an altitude of 200 to 130 km, a period of about 8 minutes. A shallow entry of -12 deg is employed for maximum observation time at the lower altitudes before burnup. Operating details for the science instruments are given in Table 3-42. The probe bus spin axis is oriented along the entry velocity vector. The UV spectrometer requires a probe spin of 60 rpm. All probe bus science is turned on 4 days prior to entry, because of available power, even though instruments other than the UV spectrometer are only required to be turned on 1 hour prior to entry. The probe bus is programmed to enter 1.5 hours after probe entry so that it can serve as a positional reference for the probes in DLBI measurements.

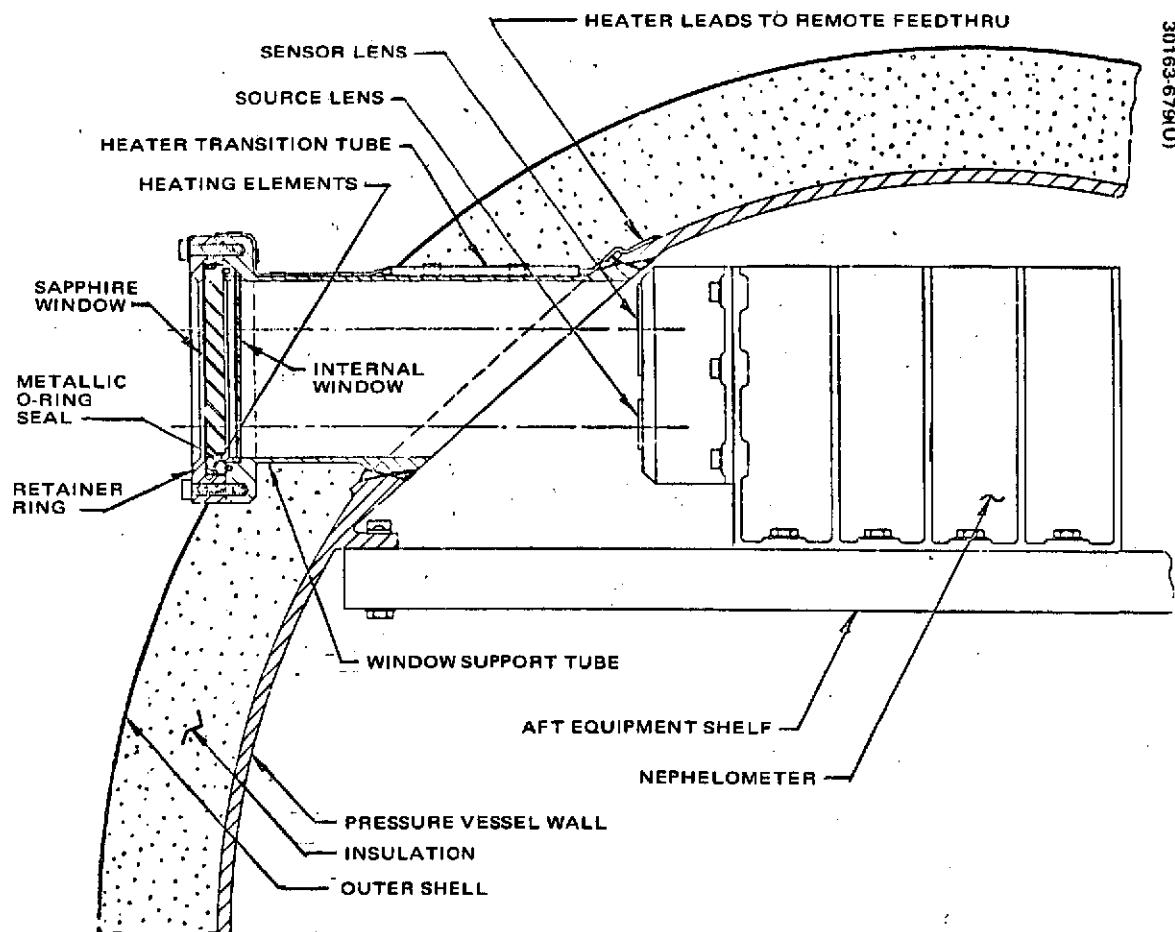


FIGURE 3-48. SMALL PROBE NEPHELOMETER INSTALLATION

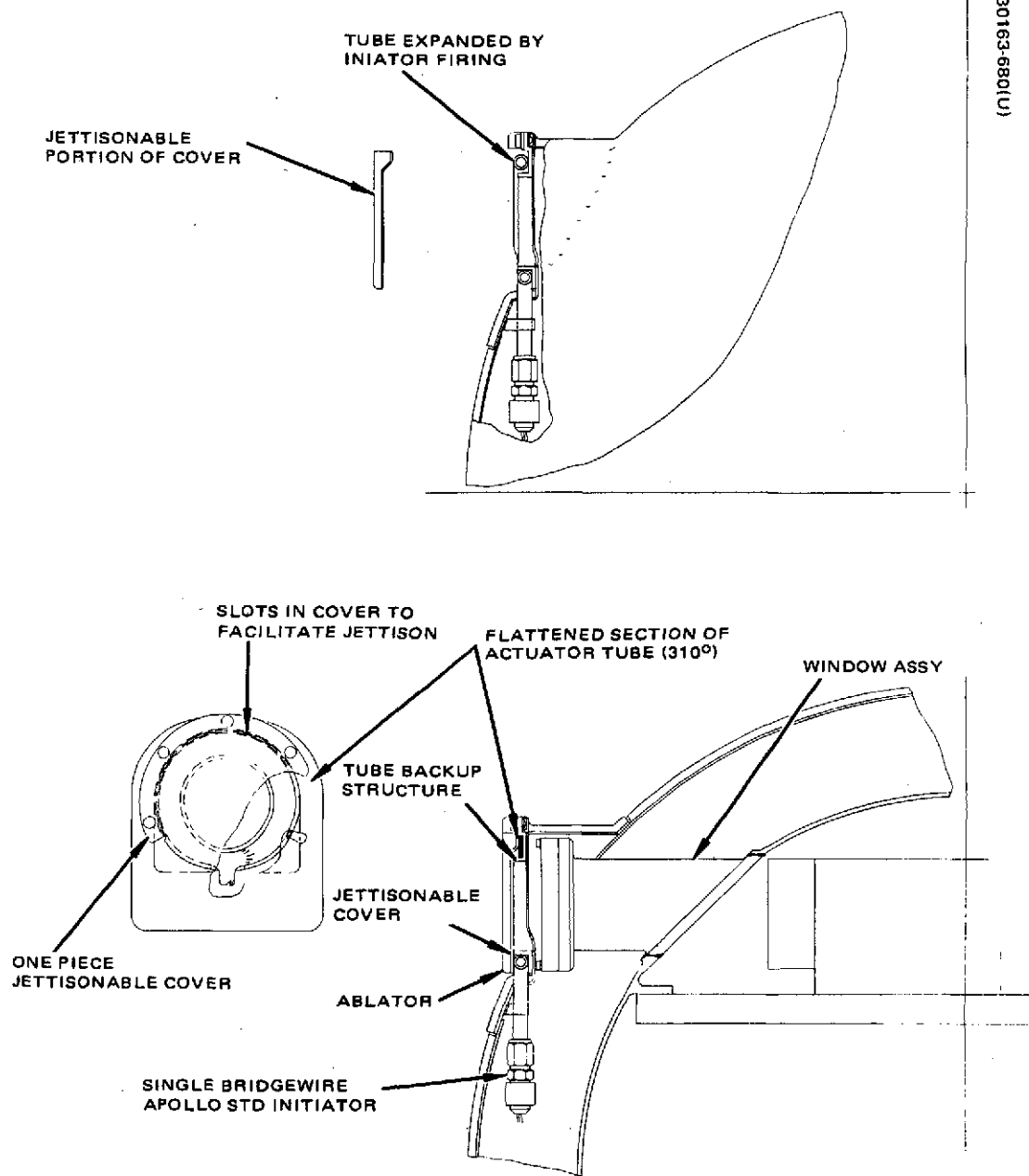


FIGURE 3-49. PYROTECHNIC ACTIVATED JETTISONABLE COVER FOR NEPHELOMETER WINDOW

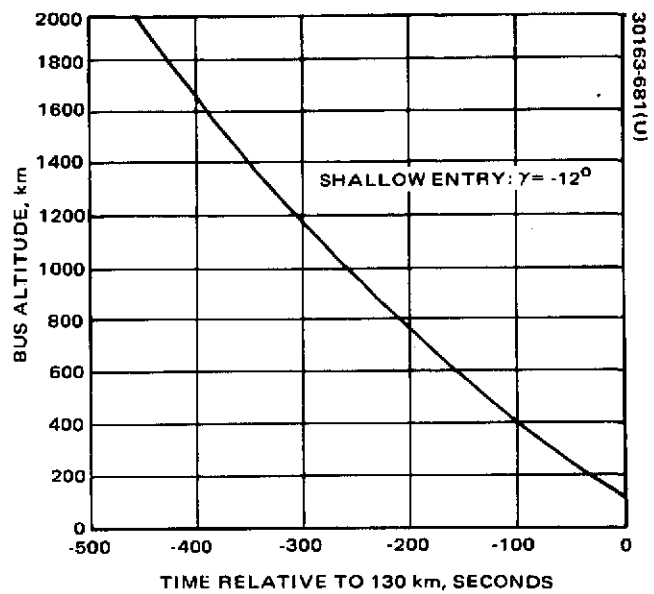


FIGURE 3-50. PROBE BUS ALTITUDE-TIME HISTORY

TABLE 3-42. OPERATING DETAILS FOR PROBE BUS INSTRUMENTS

Instrument	Operating Time	Spin	Squibs	Commands*
Neutral mass spectrometer	Entry - 1 hour	Any	1 (cover)	4
Ion mass spectrometer	Entry - 1 hour	Any	1 (cover	4
Electron temperature probe	Entry - 1 hour	Any	—	4
UV spectrometer	Entry - 4 days	60 rpm	—	6
Retarding potential analyzer	Entry - 1 hour	Any	—	4

\*Does not include on/off commands.

TABLE 3-43. PROBE BUS EXPERIMENT DATA SAMPLING REQUIREMENTS

Instrument	Measurement			Minimum Measurements	
	Description	Analog or Digital	Size, bits	Per Reference Scale Height	Per Time Interval
Neutral mass spectrometer	Science and Housekeeping	D	520	1	NA
Ion mass spectrometer	Science	D	210	3	NA
	Housekeeping	A	2	NA	60 sec
	Housekeeping	A	10	NA	5 sec
	Housekeeping	A	10	NA	5 sec
Electron temperature probe	Science	D	90	1	NA
	Housekeeping	A	8	NA	30 sec
	Housekeeping	A	8	NA	30 sec
Retarding potential analyzer	Science and Housekeeping	D	125	3	NA
UV spectrometer	Science	D	7200	NA	600 sec
	Housekeeping	A	8	NA	300 sec
	Housekeeping	A	8	NA	300 sec
	Science	D	720	1	NA
	Housekeeping	A	8	NA	60 sec
	Housekeeping	A	8	NA	60 sec
	Housekeeping	A	8	NA	60 sec



The experiment data sampling requirements are shown in Table 3-43, and data rate allocations in the Hughes design in Table 3-44. These exceed the requirements in all cases. The first density scale height above 140 km altitude (as defined in Table 5 of NASA SP-8011, Revised September 1972) has been selected as the reference measurement regime. The minimum acceptable number of measurements is specified for each instrument for this scale height. A constant data rate is assumed for each instrument from the time they are turned on, and a bus spin rate of 60 rpm. All instrument mode switching and digital data formatting is accomplished by the instrument electronics.

The mass, volume, and power allocated to the probe bus science payload are 13.8 kg (30.4 lb), 18,880 cm<sup>3</sup> (1152 in.<sup>3</sup>), and 25.8W. This includes a 15 percent increase in mass and volume and a 20 percent increase in power over the nominal payload values. These numbers represent the upper limits on the tolerances placed on the nominal values.

The Atlas/Centaur probe bus spacecraft design is shown in Figure 3-51, and the equipment shelf layout in Figure 3-52. All instruments of the probe bus are accommodated on the equipment shelf, which in turn is located in the upper section of the spacecraft. Most instruments are viewing or sampling along the forward velocity when the bus is oriented for entry measurements. Mechanical integration details for the individual instruments are given in Table 3-45.

The Thor/Delta probe bus nominal payload was presented in Table 3-14. Figure 3-53 shows a plan view of the spacecraft baseline design, and Figure 3-54 is a pictorial view, showing the fields of view. Layout of the science instruments on the spacecraft shelf is shown in Figure 3-55. Neither the magnetometer nor the UV fluorescence instruments, which required booms, are included in the Atlas/Centaur payload. New instruments in Atlas/Centaur are the UV spectrometer and the retarding potential analyzer.

Accommodation of each of the Atlas/Centaur science instruments is discussed in more detail in the following paragraphs.

#### Neutral Mass Spectrometer

The neutral mass spectrometer is desired to point within  $\pm 15$  deg of the velocity vector during encounter with the Venus atmosphere. The instrument is positioned on the equipment shelf oriented parallel to the spin axis, with a field of view as shown in Table 3-45. It is located as far as possible from those instruments affected by large magnetic fields, namely, the ion mass spectrometer, the retarding potential analyzer (RPA), and the electron temperature probe. Due clearance with other units has also been given for removal of the squib actuated cover of the instrument.

Special attention is being given to materials and processes used on the spacecraft with regard to their antigassing properties and possible subsequent detection by the instrument.

The neutral mass spectrometer will be operating continuously from at least 1 hour prior to entry and will take at least one sample in the reference scale height above 140 km. The data rate implemented is 384 bps.

TABLE 3-44. PROBE BUS SCIENCE DATA RETURN

Instrument	Data Rate Required, bps	Data Rate Provided, bps
Neutral mass spectrometer	360	384
Ion mass spectrometer	450	512
Electron temperature probe	70	128
UV spectrometer	500	512
Retarding potential analyzer	260	320
Total Science	1640	1856

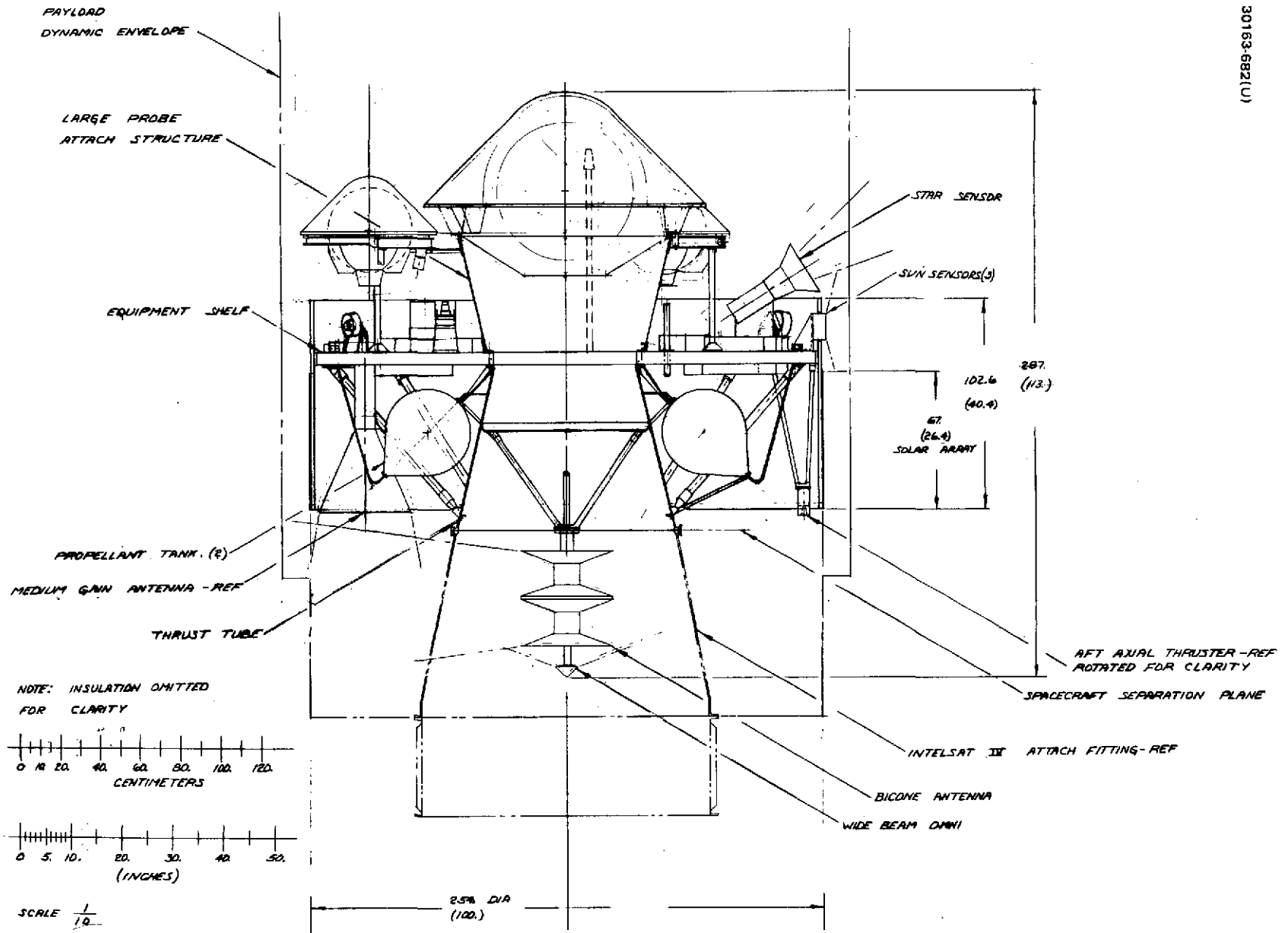


FIGURE 3-51. ATLAS/CENTAUR PROBE BUS BASELINE

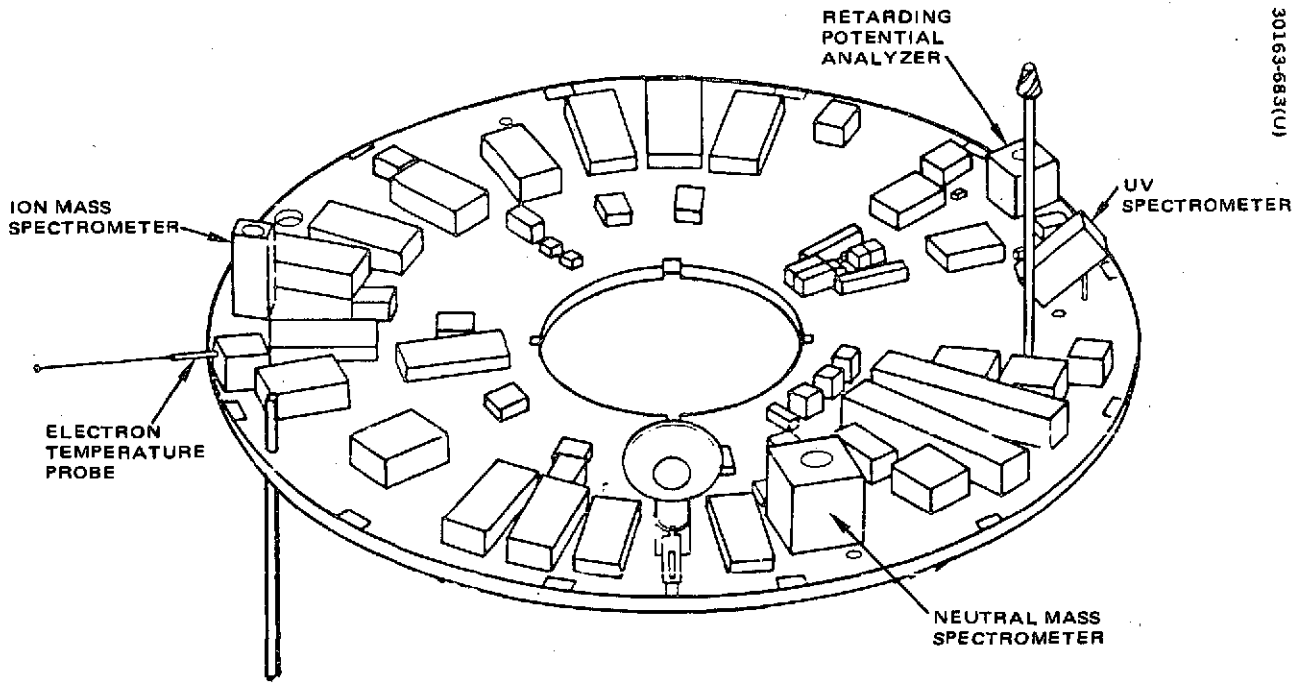


FIGURE 3-52. ATLAS/CENTAUR PROBE BUS SHELF ARRANGEMENT

TABLE 3-45. MECHANICAL INTEGRATION DETAILS FOR PROBE BUS INSTRUMENTS

Instrument	Pointing Direction	Aperture Diameter cm (in.)	Field of View	Electronics Size, cm(in.)	Sensor Size cm(in.)
Neutral mass spectrometer	Along spin axis	8.9 (3.5)	$\pm 30$ degrees	20.3 x 20.3 x 20.3 (8 x 8 x 8)	
Ion mass spectrometer	Along spin axis	7.6 (3)	$\pm 30$ degrees	22.9 x 10.2 x 11.4 (9 x 4 x 4.5)	
Electron temperature probe	90° to spin	-	-	15.2 x 12.7 x 7.6 (6 x 5 x 3)	43.2 L x 0.16 dia. (14 x 1/16)
UV Spectrometer	20° off spin	10.2 x 10.2 (4 x 4)	1 to 2 degrees conical	20.3 x 10.2 x 10.2 (9 x 4 x 4)	
Retarding potential analyzer	Along spin axis	5.08 (2)	$\pm 30$ degrees	12.7 x 12.7 x 12.7 (5 x 5 x 5)	

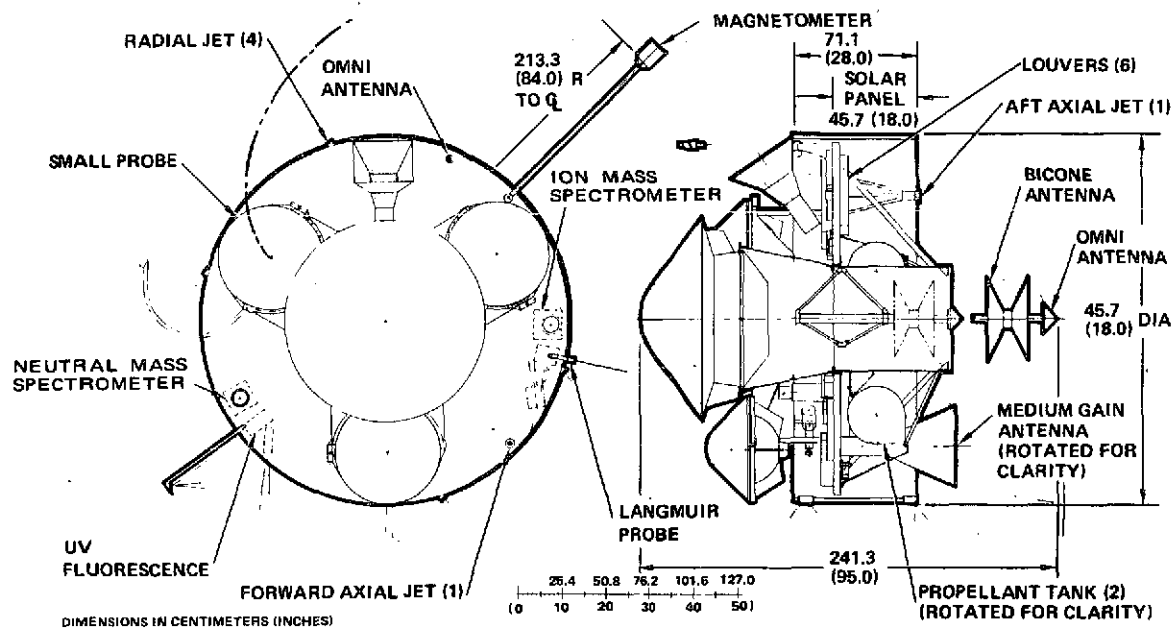


FIGURE 3-53. THOR/DELTA PROBE BUS BASELINE

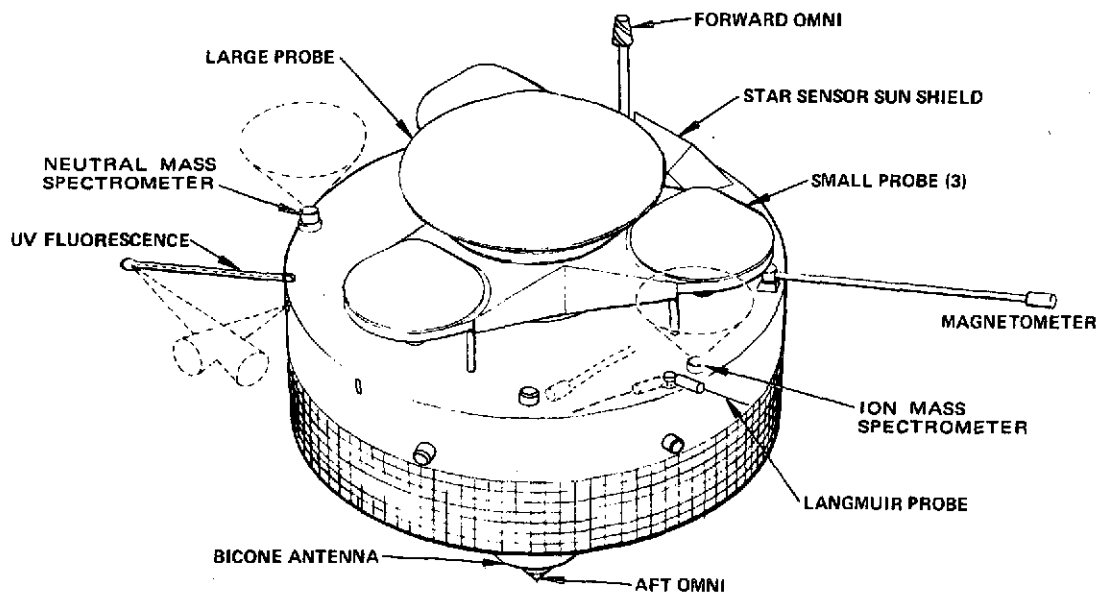
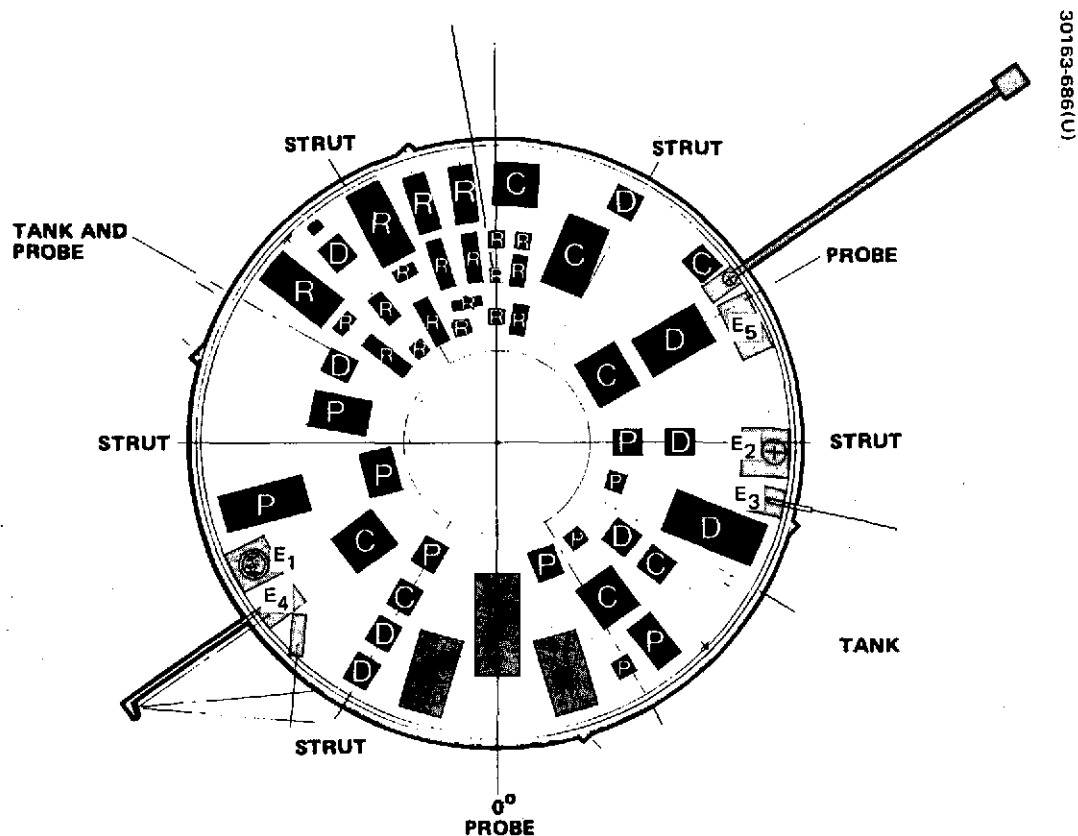


FIGURE 3-54. PROBE BUS EXPERIMENT ACCOMMODATION



#### CODE

<b>E</b>	<b>EXPERIMENTS</b>
<b>E1</b>	<b>NEUTRAL MASS SPECTROMETER</b>
<b>E2</b>	<b>ION MASS SPECTROMETER</b>
<b>E3</b>	<b>LANGMUIR PROBE</b>
<b>E4</b>	<b>UV FLUORESCENCE</b>
<b>E5</b>	<b>MAGNETOMETER</b>
<b>A</b>	<b>ATTITUDE CONTROL SUBSYSTEM</b>
<b>R</b>	<b>RF SUBSYSTEM</b>
<b>D</b>	<b>DATA HANDLING SUBSYSTEM</b>
<b>C</b>	<b>COMMAND SUBSYSTEM</b>
<b>P</b>	<b>POWER SUBSYSTEM</b>

FIGURE 3-55. THOR/DELTA PROBE BUS SHELF ARRANGEMENT

### Ion Mass Spectrometer

The ion mass spectrometer is desired to point within  $\pm 15$  deg of the velocity vector; it is oriented parallel to the spin axis. It is positioned on the equipment shelf remote from the neutral mass spectrometer and other assemblies that exhibit large fields, to minimize the deflection of low energy particles. Because the instrument measures low energy ions, precautions will be taken with the fabrication of the solar array to minimize plasma charges on the spacecraft, which, if allowed to build up, would severely distort the low energy measurements. All positive solar array exposed surfaces will be coated with an insulating material. This precaution applies also to the electron temperature probe and the RPA.

The ion mass spectrometer will be operating continuously from at least 1 hour prior to entry and will take at least three measurements in the last atmospheric scale height prior to bus burnup. The data rate implemented is 512 bps.

### Electron Temperature Probe

The electron temperature probe is required to be positioned at 90 deg to the spacecraft spin axis, with a wide field of view. This instrument, in addition to requiring protection from spacecraft charge buildup, requires a base conductive area of about 1000 cm<sup>2</sup> about the probe antenna to act as a uni-potential ground plane. It also should not be located in an antenna lobe. It consists of an electronics unit which is located on the equipment shelf, and a small whip-type antenna positioned on the substrate of the solar array, at 90 deg to the spin axis. The substrate, which is approximately 25 cm deep around the circumference of the solar array, will be finished with a high working efficiency finish (high atomic number) to act as a ground plane return to the probe and also as a return (to structure) for any plasma charge. The whip-like antenna is self-deployed with the ejection of the nose cone.

The electron temperature probe will be operating continuously from at least 1 hour prior to entry and will make at least one measurement in the last atmospheric scale height prior to bus burnup. The data rate implemented is 128 bps.

### UV Spectrometer

Of all the probe bus instruments, this instrument presents the major influence on system design. It is required to begin making planet observations about 4 days from entry (when the planet is within the instrument FOV), and to make limb scanning measurements during the final encounter phase. A spacecraft spin rate of 60 rpm is required for best instrument operation. The field of view is narrow, 1 or 2 deg. The sensor and electronics are in one unit and positioned on the equipment shelf for an unobstructed forward look angle. A mounting angle of 20 deg to the spin axis was provided in this baseline as specified, but analysis indicates a mounting angle of up to 40 deg may be required. This can also easily be accommodated.



The instrument operates at a data rate of 12 bps from entry minus 4 days to entry minus 1 hour, and at 500 bps from there on, taking at least one measurement in the last atmospheric scale height. The data rate implemented is 512 bps.

### Retarding Potential Analyzer (RPA)

The RPA is required to point within 60 deg of the velocity vector, with a wide field of view, and like the electron temperature probe requires a large conductive base area. The RPA is suspended from the equipment shelf on a bracket. This raises the instrument up to the level of the thermal blanket covering the forward end of the spacecraft. Part of the blanket around the RPA aperture will be plated to act as a ground plane to the instrument. The RPA is oriented parallel to the spin axis and has a clear unobstructed field of view of  $\pm 30$  deg.

This instrument operates continuously from at least 1 hour prior to entry and will make at least three measurements in the last atmospheric scale height. The data rate implemented is 320 bps.

### Additional Accommodation Considerations

#### Electrical Power

The electrical power provided to the science payloads of the probes and probe bus will be unregulated based on earlier tradeoff studies. For the probes the unregulated power is from +23.8 to +32.2 Vdc, and for the probe bus from +23.0 to +33 Vdc.

All power to the probe instruments is supplied by an Ag-Zn battery. The power to each instrument is both switched and parallel fused in each of the supply and return lines. Individual switching is to facilitate ground testing and the parallel fusing is to minimize inadvertent loss of an instrument due to turn-on or operating transients.

The power to the probe bus instruments is provided by both the solar array and a Ni-Cad battery. Separate and commandable power switching is provided to each instrument.

#### Telemetry

The telemetry systems of the probes and probe bus are designed to accept a mixture of digital and analog signals from the experiment. The analog encoding accuracy is 10 bits for the probes and 8 bits for the probe bus.

All telemetry and rf downlink systems are sized to accommodate the experiment requirements throughout all phases of the flight operation. Data storage is provided on both probes, but not the probe bus. The small probe storage is 512 bits and the large probe is 2048 bits. Both are sized mainly on the requirements of the accelerometer instruments to store data during the blackout period at entry.

### Commands

No command link is provided for either the large or small probes. The various sequences to switch experiments on, blow covers, or deploy sensors are provided by a flight timer activated at the time that the probes leave the bus.

The probe bus command capability is 192 pulse and 12 magnitude commands. Of these, 20 pulse commands have been allocated to the experiments. Sufficient spares remain should more be required.

### Thermal Control

During the pre-entry phases of the mission, the probe instruments are nonoperating except for brief checkouts prior to separation from the spacecraft and just before entry. During this period, the probe temperatures are controlled through the use of passive thermal finishes on the deceleration modules. The probes are thermally independent of the spacecraft, except for heater power required at the beginning of the transit between Earth and Venus. The nonoperating instrument mounting surface temperatures will be maintained within the range of  $-40^{\circ}$  to  $+38^{\circ}\text{C}$  ( $-40^{\circ}$  to  $100^{\circ}\text{F}$ ).

The probes' thermal design for the Atlas/Centaur configuration utilizes a hot pressure vessel with an internal insulation system augmented by equipment heatsinks to control the descent temperature rise. To further enhance the performance of this capacitance dominated design, good thermal conduction coupling is provided between all internal equipment and the associated structure. This achieves as close to an isothermal internal design as is practical and takes maximum advantage of the total internal thermal mass of the system. Other features of the thermal design include low conductivity mounts between the lower shelf and the vessel, mounting the top shelf off the bottom shelf rather than the vessel, and the use of low emittance internal finishes to minimize radiation interchange.

All science and support equipment inside the probes will not rise above  $52^{\circ}\text{C}$  ( $125^{\circ}\text{F}$ ) during the descent phase with the exception of the transmitter driver and output amplifiers which are allowed to rise to  $60^{\circ}\text{C}$  ( $140^{\circ}\text{F}$ ). The minimum operating limit for all probe equipment is  $-1^{\circ}\text{C}$  ( $30^{\circ}\text{F}$ ). These benign operating limits reflect the conservative and minimum cost basis for the entire Atlas/Centaur probes design.

For the probe bus the instruments are mounted to the spacecraft equipment shelf which is thermally controlled through the use of variable emittance thermal louvers and multilayer thermal insulation. The insulation system isolates the equipment shelf from large changes in environmental conditions (increasing solar intensity, varying sun angles, eclipsing), and the louvers, which are activated by shelf temperature changes, compensate for changes in the electrical dissipations on the shelf.

In the shelf thermal design consideration was given to instrument power dissipation, mounting interfaces, instrument duty cycle, and aperture characteristics.

The instrument mounting surfaces will be maintained within the range of 4° to 38°C (40 to 100°F) during operation. Detailed discussion of the spacecraft thermal design is given in Section 5 of Volume 4 (Probe Bus and Orbiter Spacecraft Trade Studies).

Instruments on the probe bus must be capable of direct sun viewing to minimize orientation constraints for attitude maneuvers.

SUPPLEMENT 3-1  
PIONEER VENUS INSTRUMENT DATA EXLP-3

## PIONEER VENUS INSTRUMENT DATA EXLP-3

## 1.0 INSTRUMENT NAME: ACCELEROMETERS

## 2.0 APPLICABLE DOCUMENTS:

Bell Aerospace, DAS VII Accelerometer Sales Brochure  
Others. See Section II of Data Book.

NASA/Ames - Hughes Meeting of 9 December 1972

NASA/Ames Preliminary Experiment Interface Descriptions -  
19 December 1972

NASA/Ames Preliminary Experiment Interface Descriptions -  
13 April 1973

## 3.0 SCIENTIFIC PURPOSE OF INSTRUMENT:

To measure the probe deceleration in the region from 141 to 70 km, also the probe perturbations from 70 km down to the surface and seismic information should the probe survive the landing. This information bridges the gap between 130 km where the bus measurement at the upper atmosphere parameter ceases, and 70 km where the lower altitude measurements are used together with measurements of the mean molecular mass of the atmosphere, and computed altitude versus time profiles, to construct profiles of atmospheric pressure, temperature and density. On the planet surface, if the probe survives, seismic measurements will be made, and will enable the detection and evaluation of the noise background at the level of 0.1 milligal or less. Surface gravity will also be measured and thus the radial distance from the planet center obtained to an accuracy of 0.4 km.

## 4.0 INSTRUMENT DESCRIPTION AND OPERATION

The large probe accelerometer is a three-axis device, with a fourth single axis unit providing a redundant measurement of axial acceleration. All four accelerometers along with the electronics are contained in one unit. The descent axis sensor of the three-axis unit must be located at or extremely close to the probe c.g. Alignment of sensor axis to probe axis is believed to be 1 min. of arc.

A single axis accelerometer, consists of a pendulous proofmass utilizing a capacitive bridge pick-off to detect acceleration forces acting on the spring supported proofmass. Rebalancing of this mass is made by electromagnetic forces when current flows through a torquer coil wound on the proofmass. The acceleration output is a

function of the amount of current required to restore the mass to a null position.

Additional circuitry in the form of higher gain amplifiers will provide seismic measurements on the planet surface to 0.1 milligal.

5.0 MECHANICAL AND THERMAL INTERFACE

WEIGHT AND MASS PROPERTIES: TOTAL 1.15 kg 2.5 lbs

ELECTRONICS:

1.15 kg 2.5 lbs

SENSOR:

SIZE:

TOTAL 665 cm<sup>3</sup> 40in<sup>3</sup>

ELECTRONICS:

665cm<sup>3</sup> 40 in<sup>3</sup>

SENSOR:

MOUNTING POSITION:

ELECTRONICS:

The descent axis accelerometer of the three-axis device will be mounted at the probe c. g.

SENSOR:

SENSOR:

ORIENTATION:

Align sensors to within 1 min. of arc of the spin axis.

FIELD OF VIEW:

N/A

APERTURE SIZE:

N/A

THERMAL:

OPERATING:

-40°C to +90°C

NON-OPERATING:

-40°C to +90°C

## 6.0 ELECTRICAL INTERFACE

### POWER:

REGULATED:	Not required
UNREGULATED:	+24VDC to +37.2VDC
AVERAGE:	2.3 watts
PEAK:	2.3 watts + 8 milliwatts per g
DUTY CYCLE:	Continuous from 141 km to a few minutes after planet impact (if probe survives). Experiment requires a warmup period prior to the 141 km. Allow 15 mins.
CONVERTER FREQUENCY:	TBD

### COMMANDS:

NUMBERS:	
TYPE:	On-Off

### TELEMETRY:

#### DATA OUTPUT:

##### ANALOG

Preliminary Axial: 0-5 vdc (8 bit accuracy required)  
Backup Axial: 0-5 vdc (8 bit accuracy required)  
Lateral: 0-5 vdc (8 bit accuracy required)  
Lateral: 0-5 vdc (8 bit accuracy required)  
Thermistor: 0-5 vdc (7 bit accuracy required)  
Turbulence: 0-5 vdc (7 bit accuracy required)

Data Sampling Requirements - There are six (6) phases and two (2) modes of operation. They are:



Data Sampling Requirement (continued)

- |                  |  |
|------------------|--|
| a) Calibration   | Turn on and transmit for a few minutes prior to release from bus.  |
| b) Entry         | From acceleration level of approximately $4 \times 10^{-4}$ g until blackout. (Considered to be 0.5 g for most probable atmosphere.) |
| c) Blackout      | Period of approximately 10 seconds starting at approximately 0.5 g.  |
| d) Post Blackout | Period from end of blackout until parachute deployment   |
| e) Terminal      | From parachute deployment until impact.  |
| f) Seismic       | Post impact  |

The two (2) modes are direct readout and storage. Table 1 gives the data rate for each cycle and mode.

TABLE 1

	Primary Axial	Backup Axial	Lateral	Lateral	Thermistor (Minimum Sampling Interval)	Turbulence
Calibration						
Entry						
Blackout *	Every 20 secs	Every 20 secs	Every 40 secs	Every 40 secs	Every 140 secs	Every 100 meters
Post-Blackout						
Terminal						
Seismic						

\* Real-time readout as well as storage of 1000 bits.

DATA TIMING SIGNALS: None

CLOCK SIGNALS: None

ELECTRICAL CONNECTORS: 1-Experiment to spacecraft signals

7.0 SPECIAL REQUIREMENTS

ORDANCE DEVICES:

NUMBER: None

TYPE:

ELECTROMAGNETIC: Meets AFBSD 62-87 MIL STD 826

MAGNETIC: N/A

RADIOACTIVE SOURCES: None

CLEANLINESS: TBD

HANDLING AND STORAGE: TBD

## 8.0 SYSTEM AND MISSION REQUIREMENTS

### ORBIT PARAMETERS:

### MISSION SCENARIO:

The following flight sequences are required for this instrument:

- 1) 1 to 5 minute checkout prior to leaving bus.
- 2) Turnon for warmup 15 mins prior to entry.
- 3) Operate from 141 km (data store during blackout) to planet surface.
- 4) Playback of stored data plus real time measurement data during descent.
- 5) Possible seismic data after impact until probe/battery end of life.

### GEOMETRIC PARAMETERS:

Little change from that shown in Sheet 7.

### TARGETING PARAMETERS:

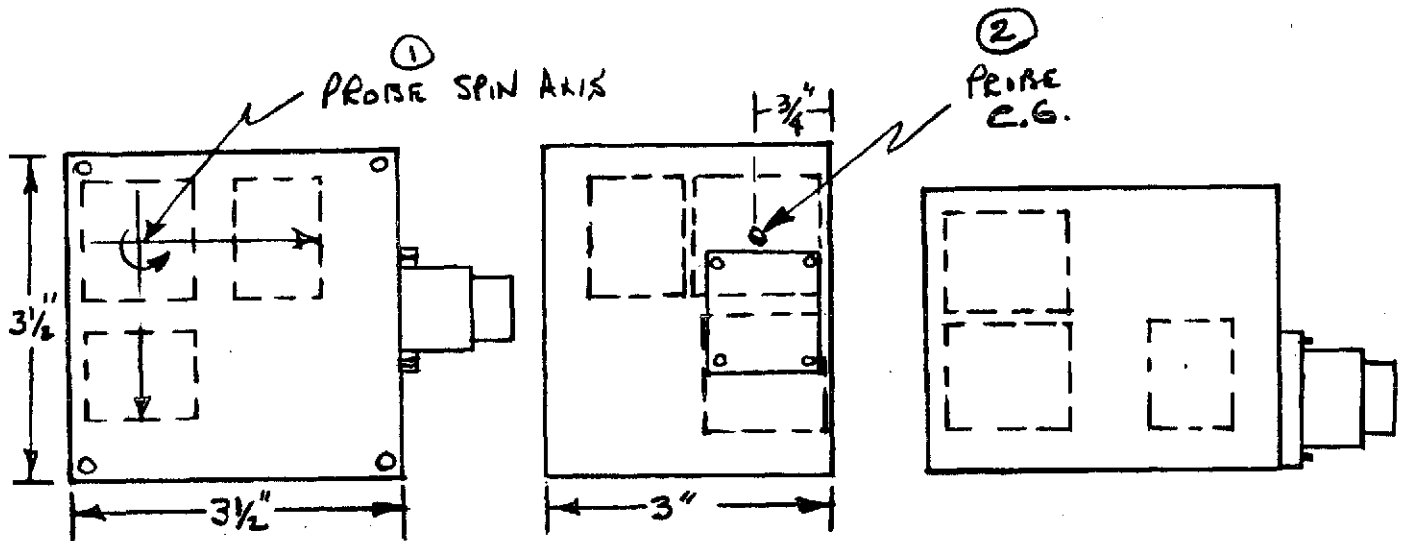
Instrument will return useful data irrespective of where targeted.

### SCANNING/TRACKING PARAMETERS:

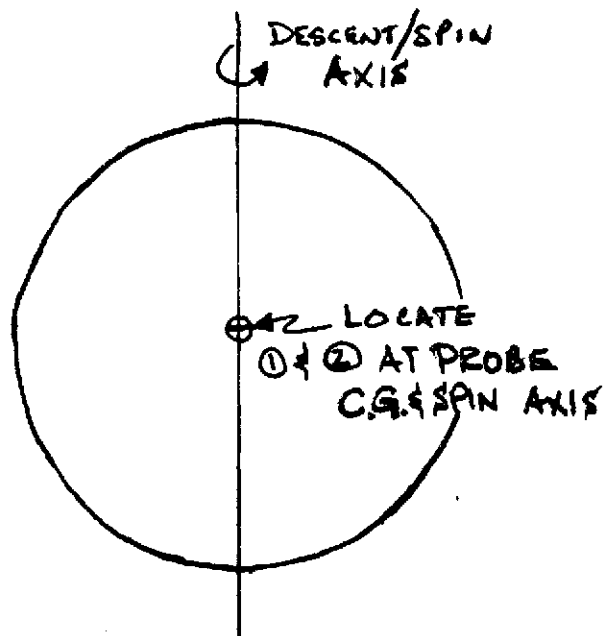
Rate of spin not critical.

### PRELAUNCH REQUIREMENTS:

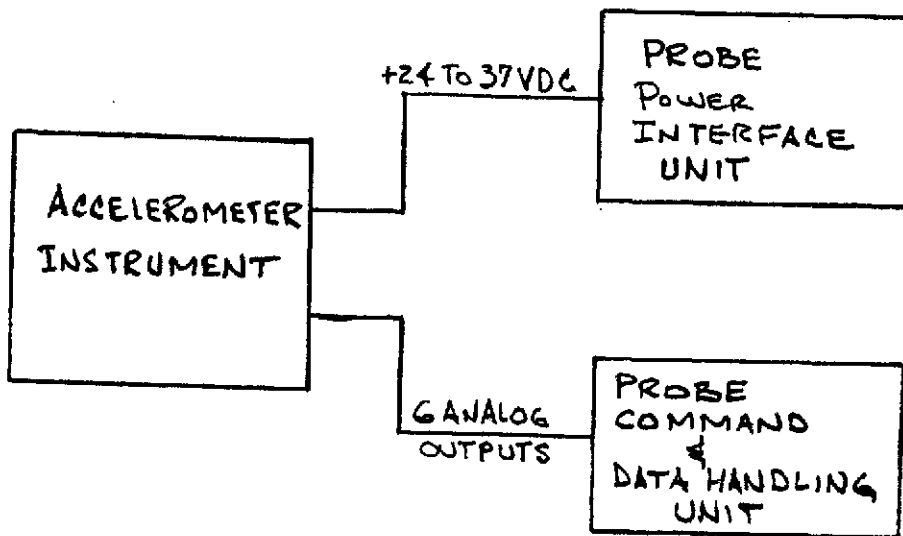
Unbilical connection to accelerometer package to allow ground check-out by current torque simulation is required.



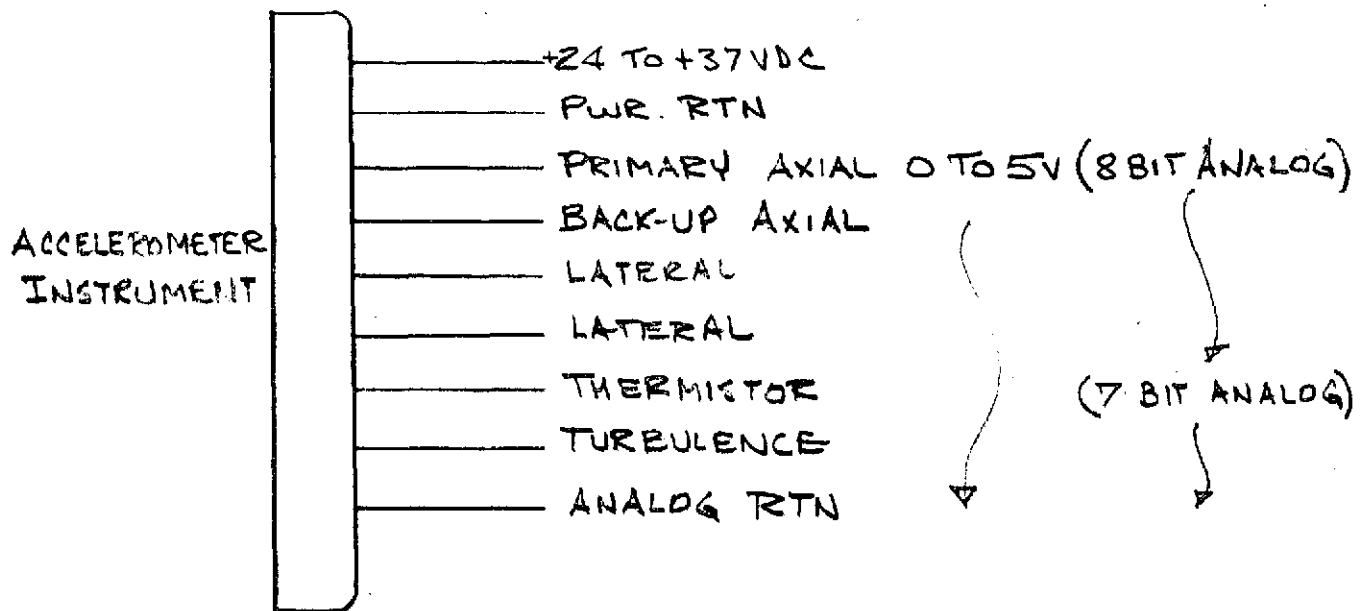
ACCELEROMETER INSTRUMENT



OUTLINE AND MOUNTING DRAWING



BLOCK DIAGRAM



ELECTRICAL INTERFACE DRAWING

#### 4. ORBITER MISSION

The Pioneer Venus orbiter mission, as currently scheduled, calls for launch of a single, spin-stabilized, solar powered spacecraft in May 1978, with an arrival date of 3 December, 6 days prior to arrival of the multiprobe mission.

The transit geometry is shown in Figure 4-1. A Type II trajectory is employed for the orbiter, whereas a Type I trajectory is employed for the multiprobe mission. Transit time is nominally 187 days for Type II, which initially moves outside the earth's orbit, whereas it is only 120 days for Type I. Thus, the multiprobe mission is not launched till August 1978, even though it arrives at the same time. Science considerations relating to the choice of a transfer trajectory for the orbiter are discussed in subsection 4.3.

The design mission is to remain in orbit for one Venus sidereal year (225 days). During the cruise phase, various instruments will make interplanetary measurements, although carried primarily for measurements during planetary orbit.

##### 4.1 SCIENCE OBJECTIVES AND REQUIREMENTS

The principal science objectives of the orbiter mission are (Reference 2-5):

- 1) Global mapping of the atmosphere and ionosphere by remote sensing and radio occultation to extend the information obtained on the vertical structure from the entry probe mission.
- 2) Global studies by in situ measurements of the upper atmosphere, ionosphere, and solar wind-ionosphere interaction region to extend and supplement the information obtained with the entry probe mission.
- 3) Studies of the planetary surface by remote sensing.

30163-154(U)

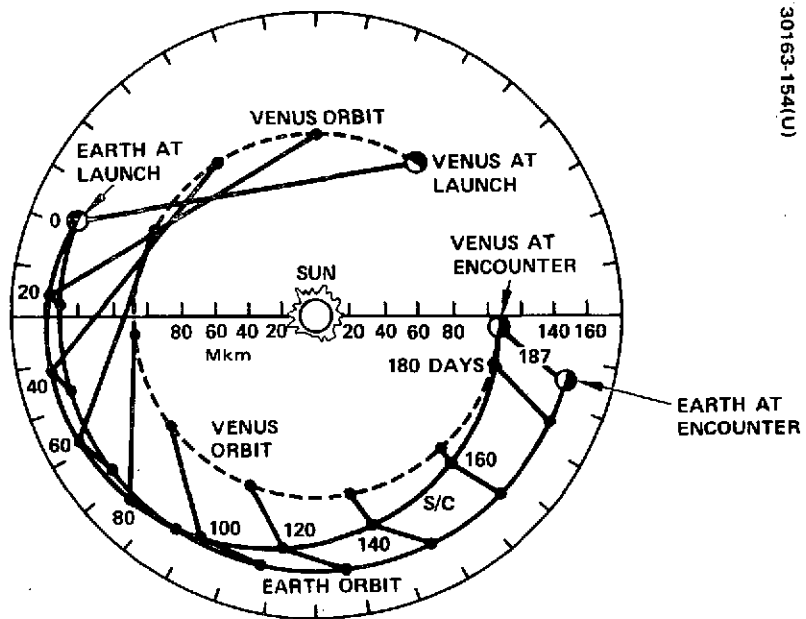


FIGURE 4-1. ORBITER TRANSIT GEOMETRY



It would also be desirable to use the orbiter mission for Venus gravimetry studies through analysis of long period orbit perturbations. Since this is difficult to achieve with low periapsis and orbital maneuvers, the NASA/ESRO Joint Working Group (JWG) recommends extension of the orbiter mission beyond the nominal lifetime in order to achieve accurate gravimetry (Reference 2-6).

In addition, the NASA/ESRO JWG recommends that during solar occultation, which occurs at the end of the nominal mission, time delay measurements be conducted for testing general relativity theory, utilizing the Venus occultation dual frequency experiment.

Science requirements for the orbiter mission indicate a preference for a highly inclined orbit plane, e. g. , greater than 60 deg (referred to the ecliptic) to near polar; for a low periapsis, e. g. , 200 km or less; for a midlatitude periapsis location, e. g. , near 45 deg, and for the periapsis location to initially exist in sunlight for a period of time prior to crossing the terminator into darkness. The operation in orbit should allow investigation over at least one sidereal year (225 earth days) and preferably one Venus rotation period (243 days) (Reference 2-6).

Apoapsis altitude may be 60,000 to 70,000 km, resulting in a 24 h orbital period, with most of the science requirements satisfied. The primary operating region for a typical science payload will be that portion of the orbit near periapsis where the altitude is below 5,000 km. Figure 4. 2 plots the nominal orbit selected, showing time from periapsis for altitudes below 5,000 km.

The initial periapsis altitude may be between 400 and 700 km with later orbital change maneuvers to lower this altitude to approximately 150 to 200 km. Solar gravity effects on the periapsis altitude will cause it to rise or fall, depending on the selected periapsis location. Periodic orbital change maneuvers will be required to maintain a designated range of periapsis altitude (150 to 200 km).

The orbit geometry with respect to the sun, earth, and Venus over the course of the mission is shown in Figure 4-3. It is seen that a solar occultation will occur shortly after the completion of a sidereal year. Earth occultations are shown in Figure 4-4. There is a 72 day period of periapsis occultations at the start of a mission and a 12 day period of apoapsis occultations late in the mission.

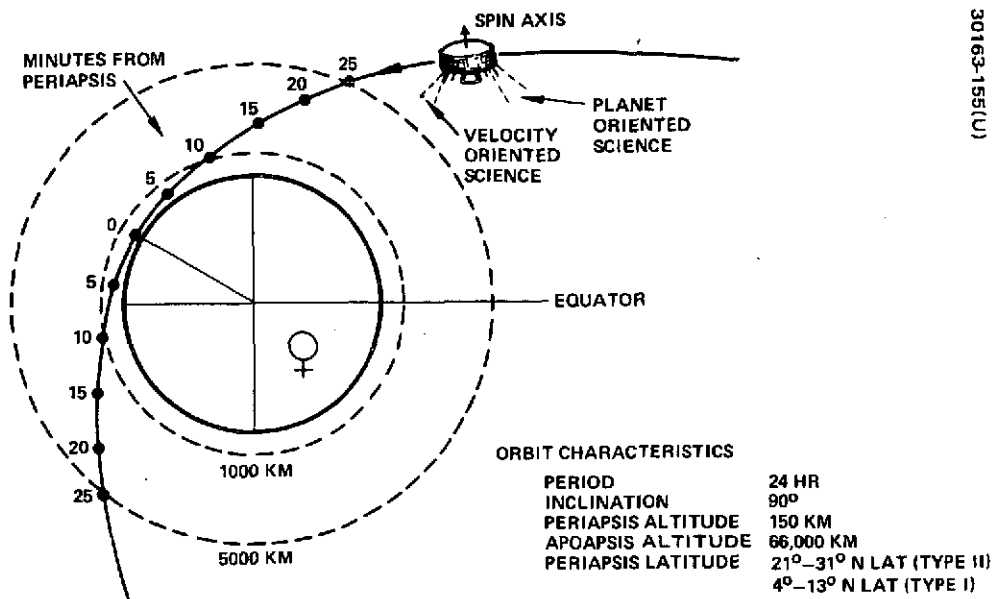


FIGURE 4-2. ORBITER MISSION

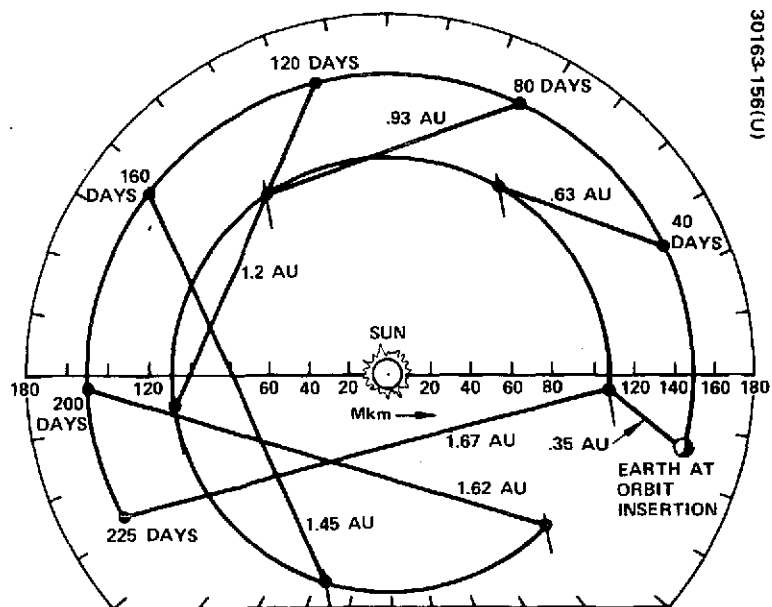


FIGURE 4-3. ORBIT PHASE GEOMETRY

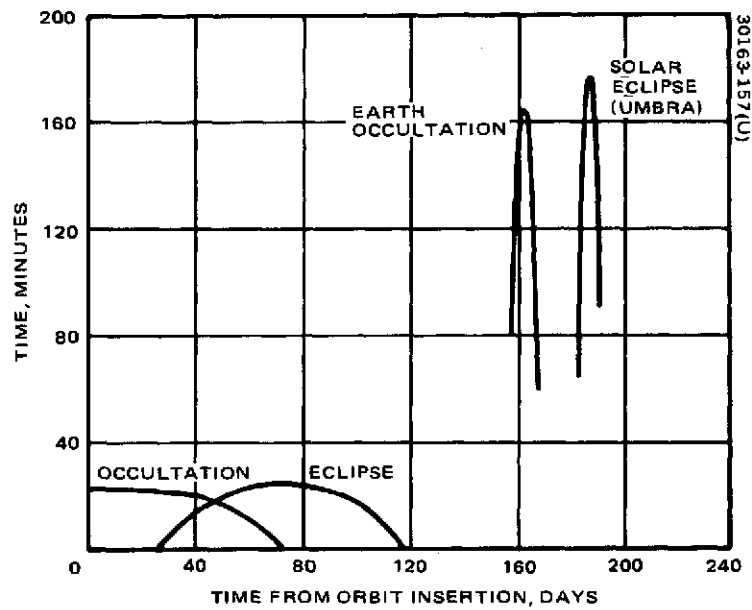


FIGURE 4-4. OCCULTATION AND ECLIPSE DURATION

## 4.2 SCIENCE PAYLOAD

An initial science payload for the orbiter mission was provided by NASA ARC on 20 September 1972 and discussed at the first Pioneer Venus science briefing on 4 October 1972. This payload consisted of eight nominal instruments and five other candidate instruments. An Atlas/Centaur version of this payload was received on 20 October, with increased weights and powers for some instruments.

On 9 November, a new baseline radio science package was defined for the orbiter by NASA ARC, and at the 1 December informal design review Hughes was directed to add a solar wind probe to the nominal payload and to delete three other candidate instruments (microwave radio-meter, electric field detector, and solar electron detector).

In January 1973, the report of a study by the NASA/ESRO JWG on the Pioneer Venus orbiter was published, containing essentially the same payload. No further updates of the orbiter payload were received until the new Atlas/Centaur payload came out in April, implementing the NASA/ESRO recommendation for a dual frequency occultation experiment.

During the study, contacts were made with a number of scientists to discuss proposed orbiter experiments. Table 4-1 provides a list of these contacts together with the orbiter science briefings.

The Thor/Delta nominal science payload is shown in Table 4-2, with the initial Atlas/Centaur figures shown in brackets where different. The nine instruments carried were: magnetometer, Langmuir probe, neutral mass spectrometer, ion mass spectrometer, ultraviolet spectrometer, infrared spectrometer, S-band radio occultation, rf altimeter, and solar wind probe. Total payload mass was 31.1 kg (68.6 lb). The Atlas/Centaur payload was slightly larger; 35.0 kg (77.2 lb).

The measurement objectives for each experiment are shown in Table 4-3, together with the operating range and sampling rate. Three instruments operate over the entire orbit, the magnetometer, solar wind probe, and uv spectrometer. The primary operating altitude of the remaining instruments was under 5,000 km, and in the case of the rf altimeter and neutral mass spectrometer, under 1000 km.

The new Atlas/Centaur nominal payload is shown in Table 4-4. The only change in the instruments is that the occultation experiment is now dual frequency, with X-band added to the S-band. Payload mass has been increased to 39.5 kg (86.9 lb).

TABLE 4-1. EXPERIMENT INTEGRATION SCIENCE CONTACTS AND BRIEFINGS  
(ORBITER MISSION)

Date	Name	Affiliation	Area of Discussion	Reference
26 Sept 72	A.I. Stewart	U of Colorado	UV spectrometer	HS 507-0224
28 Sept 72	N. W. Spencer	NASA/GSFC	Mass spectrometers	HS 507-0230
4 Oct 72	J. Sperans	NASA/ARC	First Pioneer Venus science briefing	HS 507-0225
13 Oct 72	A.G. Monfils	U of Liege	UV spectrometer	HS 507-0237
20 Oct 72	M. B. McElroy	Harvard U	Pioneer Venus science	HS 507-0253
1 Nov 72	W. B. Hanson	U of Texas	Upper atmosphere experiments	HS 507-0260
2 Nov 72	J. W. Bryan	NASA/GSFC	Orbiter altimeter and microwave radiometer	HS 507-0260
9 Nov 72	T. Grant	NASA/ARC	Orbiter rf science briefing	HS 507-0267
3 Jan 73	S. C. Chase	Hughes/SBRC	Infrared radiometer	HS 507-0368
11 Jan 73	W. E. Brown, Jr.	JPL	Radar altimeter	HS 507-0383
11 Jan 73	A. J. Kliore	JPL	RF occultation	HS 507-0383
9 Feb 73	V. R. Eshleman	Stanford U	RF occultation	HS 507-0433
9 May 73	L. H. Brace	NASA/GSFC	Electron temperature probe	HS 507-0588

TABLE 4-2. THOR/DELTA ORBITER SCIENCE PAYLOAD (DECEMBER)

Instrument	Mass		Average Power, W	Volume		Data Rate, bps
	kg	lb		cm <sup>3</sup>	in <sup>3</sup>	
Magnetometer	2.3 ( 2.5)	5.1 ( 5.5)	3.5 ( 4.0)	4310	263	3
Langmuir probe	1.6	3.5	2.0 ( 2.5)	1803	110	32
Neutral mass spectrometer	4.5 ( 5.4)	10.0 (12.0)	12.0	8193	500	17
Ion mass spectrometer	1.4 ( 1.5)	3.0 ( 3.2)	1.0 ( 2.0)	3277	200	14
Ultraviolet spectrometer	5.4	12.0	8.0	9832	600	14
Infrared radiometer	4.1 ( 4.5)	9.0 (10.0)	6.0	6555	400	7
S-band radio occultation	—	—	—	—	—	—
RF altimeter	9.1	20.0	12.0	28218	1722	300 < 400 km 5 < 1000 km
Solar wind probe	2.7 ( 5.0)	6.0 (11.0)	4.0 ( 5.0)	3933 ( 5506)	240 ( 336)	3
Total science payload	31.1 (35.0)	68.6 (77.2)	48.5 (51.5)	66138 (67711)	4036 (4132)	387 92

Comment: ( ) = Atlas/Centaur values if different from Thor/Delta

TABLE 4-3. ORBITER MEASUREMENTS

Experiment	Measurement Objective	Samples/ Min	Operating Range
Magnetometer	Magnetic fields in solar wind/ionosphere interaction	5	Entire orbit
Electron temperature probe	Electron temperature and density in ionosphere	60	<5000 km
Neutral mass spectrometer	Neutral atmosphere composition and density	0.2	<1000 km
Ion mass spectrometer	Ion composition and density of upper atmosphere	0.4	<5000 km
UV spectrometer	Minor constituents of atmosphere, air glow	2	Entire orbit
IR radiometer	Thermal structure of atmosphere above cloud tops	10	<5000 km
RF occultation	Dispersive absorption and scattering by cloud particles	—	Occultation periods
RF altimeter	Surface height variation, reflectivity, and roughness	5	<1000 km
Solar wind probe	Flux and energy distribution of solar wind particles	5	Entire orbit

TABLE 4-4. ATLAS/CENTAUR ORBITER NOMINAL PAYLOAD (APRIL)

Instruments	Mass <sup>(1)</sup>		Volume <sup>(2)</sup>		Average Power, W <sup>(3)</sup>	Data Rate, bps <sup>(4)</sup>	Remarks
	kg	lb	cm <sup>3</sup>	in <sup>3</sup>			
Magnetometer	3.5	7.7	3937	240	4.0	3/32	3 bps in cruise and upper orbit; 32 bps in bow shock region
Solar wind analyzer	5.0	11.0	5507	336	5.0	3	
Electron temperature probe	1.4	3.0	1967	120	2.5	24	
Neutral mass spectrometer	5.4	12.0	8195	500	12.0	100	
Ion mass spectrometer	1.5	3.2	3278	200	2.0	100	
UV spectrometer	5.5	12.0	6556	400	6.0	34	6 channel
IR radiometer	5.5	12.0	6556	400	6.0	100	
X-band occultation	2.7	6.0	3937	240	12.0	—	
Radar altimeter	9.0	20.0	9834	600	40.0	50	
Totals	39.5	86.9	50760	3036	89.5	414/443	

(1) Nominal mass shown; assume tolerances of +15, -10 percent.

(2) Nominal volumes shown; assume tolerance of  $\pm 15$  percent.

(3) Nominal average power shown; assume tolerance of +20, -10 percent.

(4) Typical data rates. See Table 4.4-3 for details.



Other candidate instruments are shown in Table 4-5. The electric field detector and microwave radiometer have been restored to the other candidate category, and a spin scan photometer added. A thermal/suprathermal particle detector listed previously has been deleted.

#### 4.3 TRADEOFF STUDIES

Experiment integration study tasks relating to the orbiter mission are listed in Table 4-6, with a brief statement of task objective. EX1 and EX2 included both multiprobe and orbiter studies, EX12 was unique to the orbiter. Orbiter magnetometer considerations are identical to those of the probe bus, thus the EX15 study has been adequately treated in subsection 3.3. The orbiter portions of the other studies are discussed in this section.

Two science related study tasks from other areas are also listed in Table 4-6: mission analysis study task MS 25 on selection of the transfer orbit type and periapsis location, and communications study task CM 19, which was reoriented to the impact of the dual frequency occultation experiment on communications subsystems. Results of these tasks are presented here as well.

##### Spin Axis Orientation/Science Requirements (EX12)

The selection of the spacecraft spin axis orientation is of prime importance in that the total spacecraft configuration as well as several key subsystem designs depend critically on this selection. The science performance is also affected very markedly by this selection.

This study has shown that for all planet (Venus) -oriented, velocity-oriented, and sun-oriented science experiments the spin axis perpendicular to the ecliptic is superior to the alternate of spin axis directed to the earth. Other experiments do not have preference for one over the other. From the spacecraft mechanization standpoint, spin axis perpendicular to the ecliptic also results in simpler thermal and power subsystem designs, as well as less overall spacecraft weight. A third alternative, spin axis perpendicular to the orbit plane, was considered to be excellent from the planet and velocity-oriented science point of view, but its cost in fuel is prohibitive.

While there is some diversity in the desired orbit characteristics, all of the experiments can be satisfied with the nominal orbit selected for evaluation purposes in this study, i. e. , a 24 h polar orbit with a 150 km altitude periapsis located at approximately 30°N latitude, resulting from the selection of a Type II Earth-Venus transit trajectory. This orbit has

the spacecraft traversing through each periapsis from north to south relative to the planet Venus. An alternate periapsis selection, also resulting from the Type II trajectory but with periapsis passage reversed in direction from south to north, is located at approximately  $45^{\circ}\text{S}$  latitude. Although minor changes in experiment placements and field-of-view orientations do have to take place for the alternate periapsis selection in order to maximize science return, the major conclusion to be reached in this study as to what spin axis orientation is best from the overall standpoint, i. e. , science return and system mechanization complexity, is not affected by the specific periapsis selection. Thus, the nominal orbit will be adopted for all subsequent discussions.

Tables 4-7 and 4-8, respectively, are summaries of the estimated nominal and other candidate instrument operating requirements in terms of pointing as well as primary altitude regimes. There are five classes of pointing requirements: 1) no preference, 2) velocity oriented, 3) planet oriented, 4) earth oriented, and 5) sun oriented. Except for the radar altimeter which is estimated to require a  $\pm 1$  deg pointing accuracy relative to the instantaneous radius vector at some point during the spin cycle and the rf occultation experiment which requires the high-gain telemetry antenna pointed directly at earth during occultations by Venus, none of the other experiments requires precise pointing. Another important observation is that all of the planet and velocity-oriented instruments have their primary measurement altitude regimes near periapsis, extending to perhaps 1000 to 2000 km in altitude.\* The planet-oriented instruments, with the exception of the altimeter, are all of a scanning type. Thus, a figure-of-merit that can be used in this evaluation is the slant range measurement distance from these instruments to a given point on the Venus surface being scanned, this distance being inversely related to the resolution. For the velocity-oriented and sun-oriented instruments, the minimum angle during each spin cycle that a particular instrument makes with the instantaneous velocity or the sun vector can be used as a figure-of-merit.

Another consideration is the percentage of the total mission after injection into Venus orbit that each instrument can be expected to make satisfactory measurements. Although no requirements can be stated at this time, it would be desirable if satisfactory measurements could be made by all instruments over one hundred percent of all the orbits or at all available opportunities during the mission.

Implicit in the choice of the periapsis location at near midlatitude is the desire to scan the northern or southern hemisphere at low measurement distances, it being recognized that measurement over the entire

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\* This does not mean that some of these instruments do not make measurements at higher altitudes, only that the altitudes of most interest are lower.

TABLE 4-5. ATLAS/CENTAUR ORBITER, OTHER CANDIDATE INSTRUMENTS

Instruments	Mass <sup>(1)</sup>		Volume <sup>(2)</sup>		Average <sup>(3)</sup> Power, W	Data <sup>(4)</sup> Rate, bps	Remarks
	kg	lb	cm <sup>3</sup>	in <sup>3</sup>			
AC electric field detector	2.3	5.0	2950	180	3.0	2.25	
Microwave radiometer	11.4	25.0	9834	600	15.0	—	
Spin-scan photometer	9.0	20.0	8195	500	15.0	—	

(1) Nominal mass shown; assume tolerance of +15, -10 percent.

(2) Nominal volumes shown; assume tolerance of ±15 percent.

(3) Nominal average power shown; assume tolerance of +20, -10 percent.

(4) Typical data rates. See Table 4-15 for details.

TABLE 4-6. EXPERIMENT AND SCIENCE-RELATED  
TASK OBJECTIVES

EX1: Payload Tradeoff Analysis

Study accommodation of the other candidate instruments in addition to the nominal payload.

EX2: Payload Design Integration

Identify and resolve payload accommodation problems by understanding the instrument and science requirements and relating them to integration requirements.

EX12: Spin Axis Orientation/Science Requirements

Evaluate the relative quantity and quality of science data return in the orbiter case for spin axis parallel or perpendicular to the ecliptic.

EX15: Magnetometer Studies

Determine requirements and location for the magnetometer on the orbiter.

MS 25: 1978 Orbiter Transit Trajectory Selection

Study tradeoffs affecting selection of transit trajectory type and orbiter periapsis location.

CM 19: Orbiter Radio Science Impact on Communications Subsystems

Determine impact of orbiter radio science requirements on communications subsystem design.

TABLE 4-7. ORBITER EXPERIMENT POINTING PREFERENCES -  
NOMINAL PAYLOAD INSTRUMENTS

Experiment	Instrument Pointing Classification	Pointing Requirement	Measurement Altitude Regime*
Magnetometer	(N) No preference	None	Entire orbit
Electron temperature probe	(V) Velocity oriented	Forward hemisphere	Periapsis to 2000 km
Neutral mass spectrometer	(V) Velocity oriented	Velocity $\pm 30$ deg	Periapsis to 1000 km
Ion mass spectrometer	(V) Velocity oriented	Velocity $\pm 30$ deg	Periapsis to 2000 km
UV spectrometer	(P) Planet oriented	Scan Venus limb	Near periapsis (also scans Venus disk and space at higher altitudes)
IR radiometer	(P) Planet oriented	Scan Venus disk	Periapsis to 2000 km
RF altimeter	(P) Planet oriented	Along instantaneous radius vector $\pm 1$ deg	Periapsis to 1000 km
RF occultation	(E) Toward Earth	Antenna toward Earth	Arbitrary (whenever occultation occurs)

\*Primary region of interest. Some of these instruments may operate out to 4000 or 5000 km.

TABLE 4-8. ORBITER EXPERIMENT POINTING PREFERENCES -  
OTHER CANDIDATE INSTRUMENTS

Experiment	Instrument Pointing Classification	Pointing Requirement	Measurement Attitude Regime
Solar wind probe	(S) Toward sun	Sun large angular tolerance	Entire orbit
Thermal/suprathermal particle detector	(V) Velocity oriented	Forward hemisphere	Periapsis to 2000 km
Electric field detector	(N) No preference	None	Entire orbit
Solar electron detector	(S) Sun oriented	Sun large angular tolerance	Entire orbit
Microwave radiometer	(P) Planet oriented	Scans Venus disk	Periapsis to 2000 km

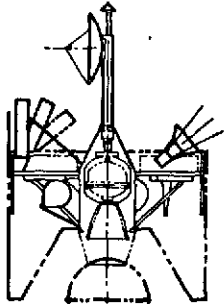
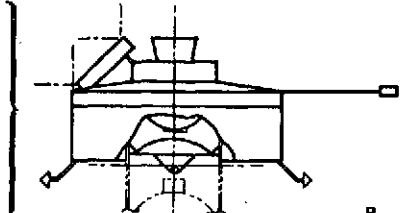
planet surface at low measurement distances is impossible because of the nature of the orbit. Thus, latitude coverage from equator to one of the poles, but not both, is used as another figure-of-merit.

The viable options for the spin axis orientation are shown in Figure 4-5. The three options are: 1) perpendicular to the ecliptic, 2) directed to earth, and 3) perpendicular to orbit plane. Two orbiter spacecraft configurations are shown. For case (1), the spacecraft features solar cells only around the drum, and a mechanically despun antenna. The electronically scanned radar altimeter is shown in several possible fixed but adjustable mounting positions. This is the baseline design concept. For cases (2) and (3), the designs are identical in that the antenna is fixed with its boresight slightly offset from the spin axis for conical scanning. The difference in design between (2) and (3) is merely in the amount of additional propellant necessary to point the spin axis, therefore the antenna, back to earth each orbit for a finite data dump period. A fourth possibility, that of a spin axis always perpendicular to the orbit plane without need for repositioning to establish downlink to earth, was not studied because that design combines the complexity of a mechanically despun antenna with an added elevation gimbal requirement, together with the more complex thermal and power subsystem design of (2). It was felt that the additional complexity was not warranted in view of the fact that most, if not all, science objectives apparently can be met with the simpler versions studied.

#### Baseline Design (Spin Axis $\perp$ Ecliptic) Science Coverage

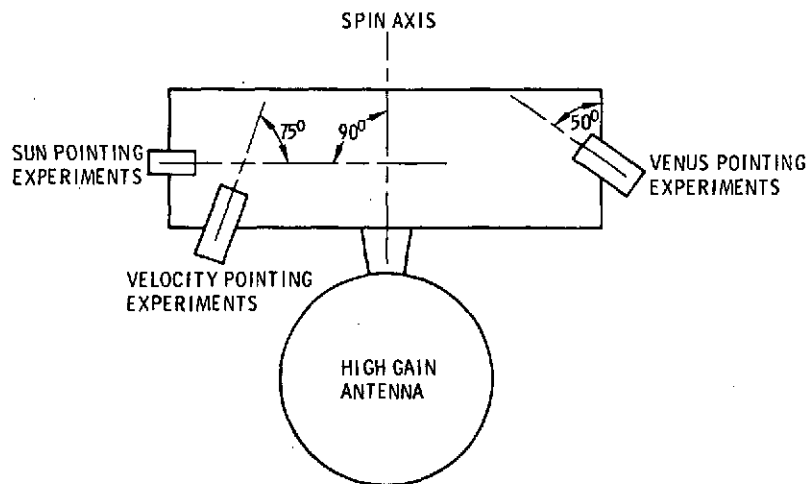
For the 24 h polar orbit with periapsis at approximately  $30^{\circ}\text{N}$  latitude, the "optimum" placements for the various types of instruments are shown in Figure 4-6. The relationships between the spin axis, the orbit plane and the direction of the earth are depicted in the right-hand figure in Figure 4-7. The instrument scan patterns relative to the orbit and the planet are independent of the positions of the earth and sun in this case. This is one of the great advantages of this configuration because there is no degradation of science coverage performance over the course of a Venusian year.

Except for the radar altimeter, the planet (Venus) -oriented experiment performance is shown in Figure 4-8. For the specific orbit selected, there is a minimum measurement distance for every latitude as depicted in the insert. The baseline performance over all northern latitudes is shown to differ only slightly from this minimum distance, specifically less than 10 percent above the minimum. Thus, from the resolution standpoint, the planet-oriented experiment performance is nearly ideal. Another advantage is that scanning of the surface is performed in roughly the east-west direction (as opposed to north-south).

SPIN AXIS ORIENTATION	FEATURE	CONFIGURATION
1. PERPENDICULAR TO ECLIPTIC	SIMPLEST THERMAL CONTROL & POWER SUBSYSTEM DESIGNS	 A
2. DIRECTED TO EARTH 3. PERPENDICULAR TO ORBIT PLANE (AROUND VENUS)	FIXED HIGH GAIN ANTENNA BEST FOR PLANET AND VELOCITY POINTED EXPERIMENTS	 B

30163-158(U)

FIGURE 4-5. ORBITER SPIN AXIS ORIENTATION OPTIONS



30163-159(U)

FIGURE 4-6. EXPERIMENT DEPLOYMENT (FOR TYPE II TRAJECTORY AND PERIAPSIS SELECTION)



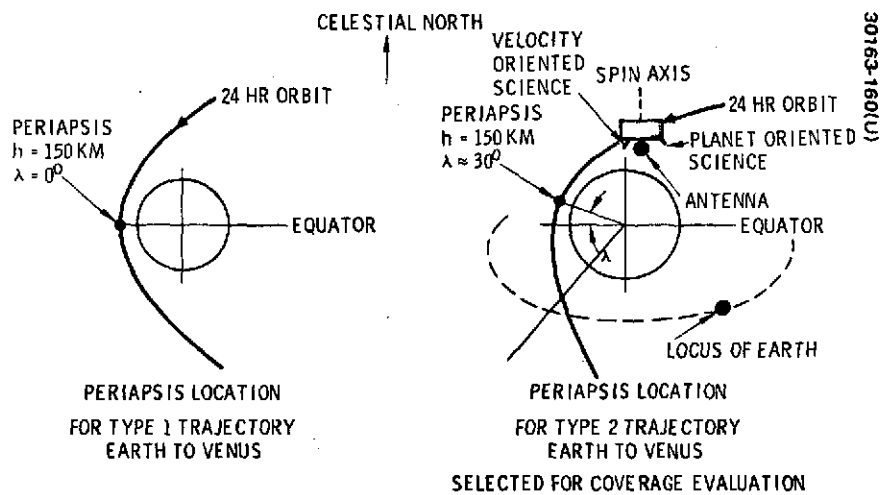


FIGURE 4-7. ORBIT AND PERIAPSIS SELECTIONS

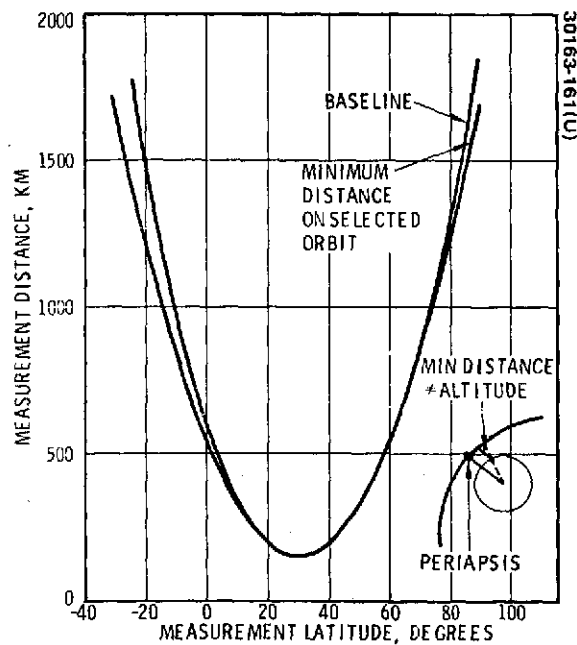


FIGURE 4-8. VENUS POINTING EXPERIMENT  
MEASUREMENT RANGE VERSUS LATITUDE (FOR  
TYPE II TRAJECTORY AND PERIAPSIS  
SELECTION)

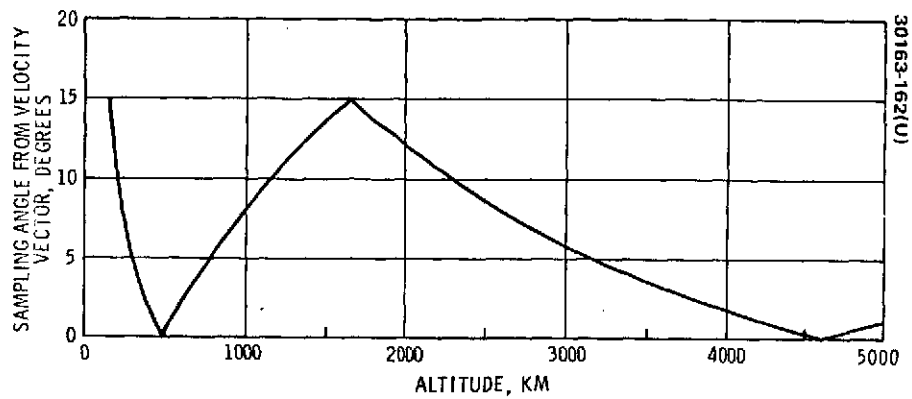


FIGURE 4-9. VELOCITY POINTING EXPERIMENT SAMPLING ANGLE VERSUS ALTITUDE (FOR TYPE II TRAJECTORY AND PERIAPSIS SELECTION)

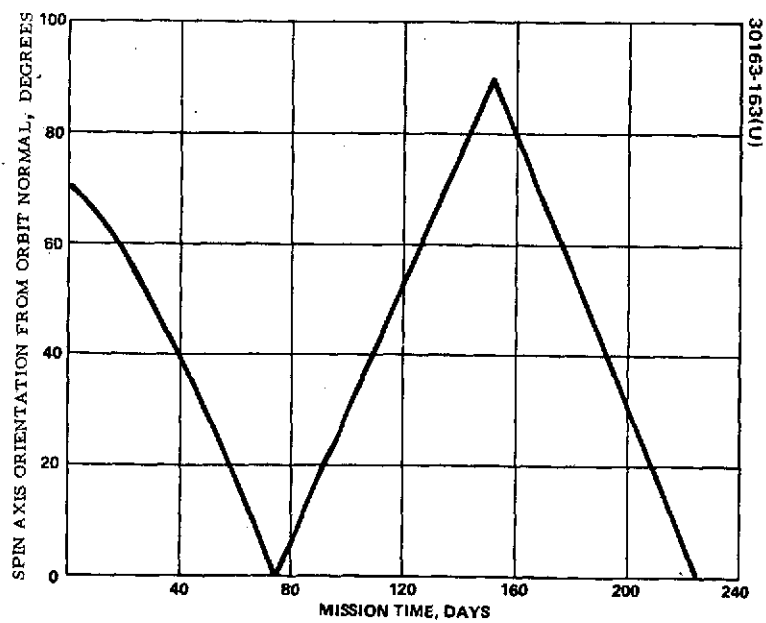


FIGURE 4-10. SPIN AXIS ORIENTATION – SPIN AXIS DIRECTED TO EARTH

This means that if for some reason the taking of this type of data had to be omitted for some restricted number of orbits, resumption of these experiments at a later date could still cover the surface area omitted even if the measurement distances had to be somewhat greater. The same cannot be said for a north-south type scan such as would be the case if the spin axis were normal to the orbit plane. There, certain longitude sectors would be lost.

For the velocity-oriented experiments, Figure 4-9 shows the sampling angle versus altitude. From the 150 km periapsis to 5000 km altitude, the sampling angle is 15 deg or smaller, as compared to an acceptable value of, say, 30 deg.

For the radar altimeter, an assumed  $\pm 45$  deg elevation boresight freedom allows measurements to be taken along the local vertical sometime during each spin cycle so that all northern latitudes are covered.

Table 4-9 is a summary of the baseline science coverage performance. It can be seen that all types of experiments can be operated either ideally or nearly so, in accordance with the measures adopted here for figures-of-merit.

#### Alternate Design (Spin Axis Directed to Earth) Science Coverage

This design has a varying spin axis to orbit plane geometry due to the relative motion between the earth and the orbit plane. The angle between the spin axis and the orbit normal is shown in Figure 4-10. Because of this wide swing, the optimum field-of-view direction of all planet-oriented, velocity-oriented and sun-oriented experiments is assumed to be radial, i. e. , perpendicular to the spin axis, there apparently being no better direction available which would be good over the entire Venusian year. The optimum direction of spin-axis orientation for the planet- and velocity-oriented experiments is then along the orbit normal. Figure 4-11 shows the maximum angle between the actual spin-axis direction and the optimum versus the percent of mission duration. For example, this angle is less than 20 deg for roughly 20 percent of the mission. For the planet-oriented experiments, the measurement distances for all northern latitudes are shown in Figure 4-12, as a function of this angle. The performance varies from an ideal situation when the angle is zero to something significantly less than ideal when the angle is 90 deg. Measurement distances can be many times the minimum distances. Thus, one may conclude that the performance over the entire mission is highly inconsistent. Coverage of all northern hemisphere points with near ideal resolution is therefore highly doubtful.

TABLE 4-9. BASELINE DESIGN SCIENCE PERFORMANCE  
SUMMARY (SPIN AXIS  $\perp$  ECLIPTIC)

Experiments	Percent Mission Data Coverage	Performance
Velocity oriented	100	Measurement between periapsis and 5000 km at less than 15 deg sampling angle
Sun oriented	100	Ideal; scan is in ecliptic plane
Earth pointed	When applicable	Ideal; no need to interrupt downlink
Planet oriented	100	Measurement of all northern latitudes taken within +10 percent of minimum distance  Altimeter coverage of all northern latitudes achievable by $\pm 45$ deg elevation boresight freedom

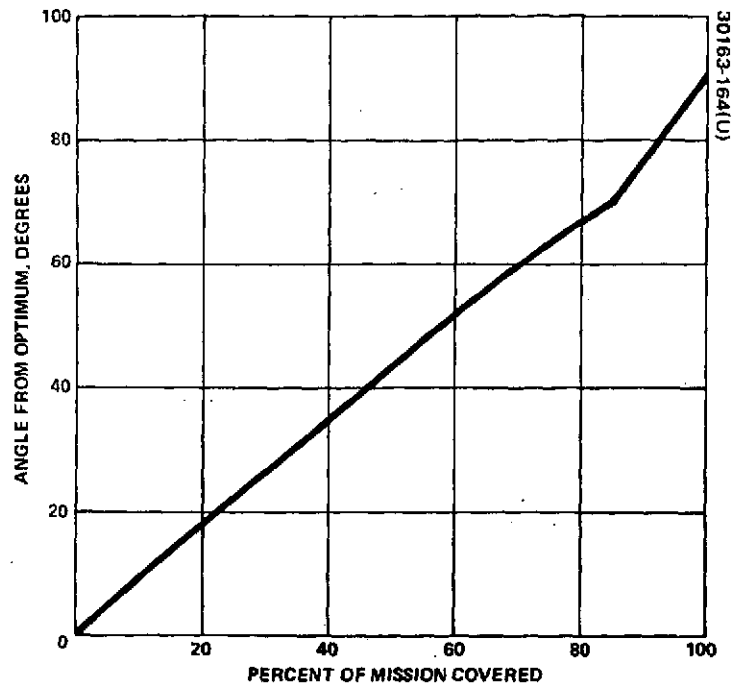


FIGURE 4-11. VENUS POINTED EXPERIMENT  
COVERAGE – SPIN AXIS DIRECTED TO EARTH

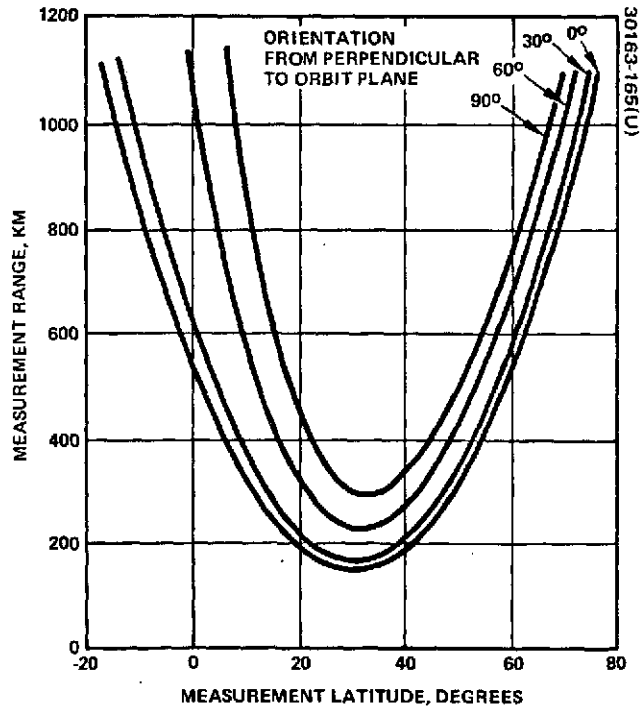


FIGURE 4-12. VENUS POINTED EXPERIMENTS  
MEASUREMENT RANGE – SPIN AXIS DIRECTED  
TO EARTH

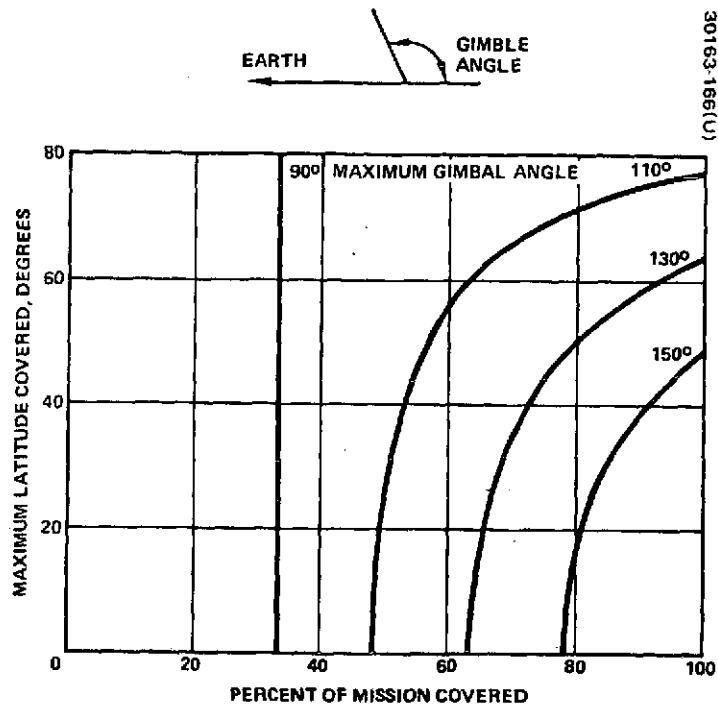


FIGURE 4-13. ALTIMETRY COVERAGE -  
SPIN AXIS DIRECTED TO EARTH

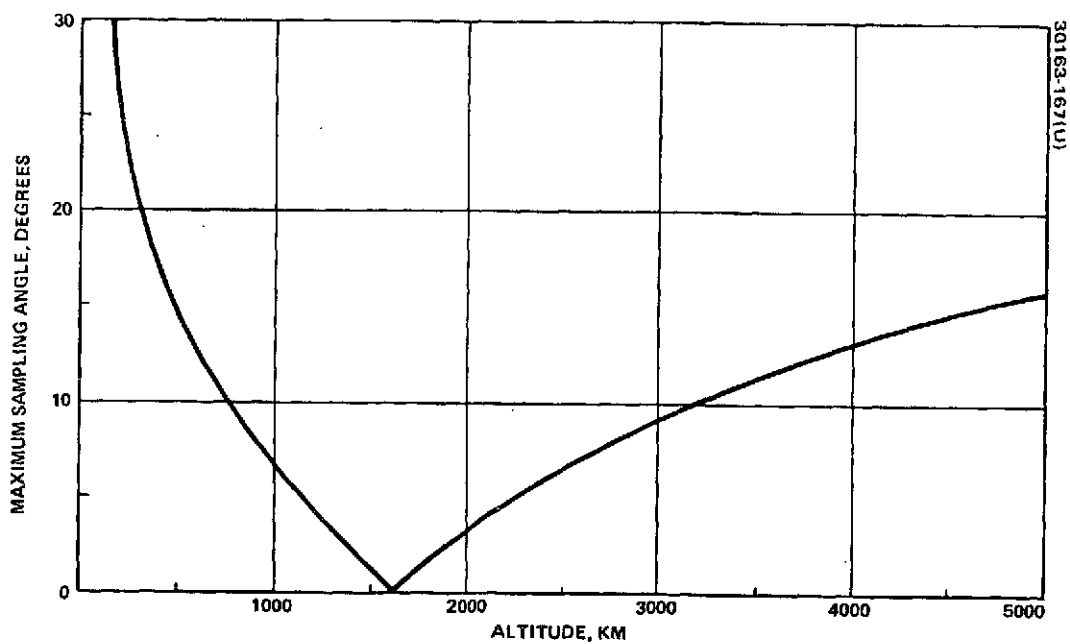


FIGURE 4-14. VELOCITY POINTED EXPERIMENT COVERAGE -  
SPIN AXIS DIRECTED TO EARTH

For the radar altimeter, this varying geometry results in large elevation gimbal or boresight angle requirements if one wishes to cover all northern latitudes at near 100 percent of the mission opportunities. Figure 4-13 shows the relationship between latitude coverage, gimbal freedom and percent mission coverage. For the selected electronically despun antenna design, 90 deg is probably an achievable limit. Only over 35 percent of the mission can all latitudes be covered. Thus, from the altimetry standpoint, this orientation results either in marginal coverage or in severe requirements for gimbal or boresight freedom.

For the velocity-oriented experiments, the geometry varies from nearly ideal to something less. Figure 4-14 is a plot for the worst case situation, of the sampling angle versus altitude. A maximum angle of 30 deg can be achieved from periapsis to 5000 km. This is not so good as the baseline performance but is probably acceptable.

The sun-oriented experiments also do not have ideal pointing over the entire mission. Figure 4-15 shows the minimum angle versus mission time. If the acceptable limit for this angle is 90 deg, then this may not be too great a problem.

Table 4-10 summarizes the alternate design science coverage performance. The major deficiency lies in the planet-oriented science coverage, as compared to the baseline.

#### Alternate Design with Reorientation per Orbit (Spin Axis Perpendicular to Orbit Plane)

If the spin axis is allowed to point along the orbit normal during periapsis passage and is reoriented later, perhaps near apoapsis, for downlink data dump, the coverage for all velocity- and planet-oriented experiments is then optimum. If, in addition, the spin axis is directed when appropriate for the sun-oriented experiments, these could also have ideal performance. The fuel cost for these maneuvers over the course of one Venusian year is shown in Figure 4-16. To do the orbit normal maneuvers costs roughly 11.8 kg (26 lb), a prohibitive amount in view of the very tight weight situation. In addition, these maneuvers require once per orbit downlink interruption, highly undesirable from the mission safety and operations point of view.

Table 4-11 shows an overall pro and con comparison of the mechanization and system design features of the spacecraft shown in Figure 4-5. It is apparent that the baseline design is superior from the standpoint of mass. It is also felt that the baseline is less complex mechanization-wise.

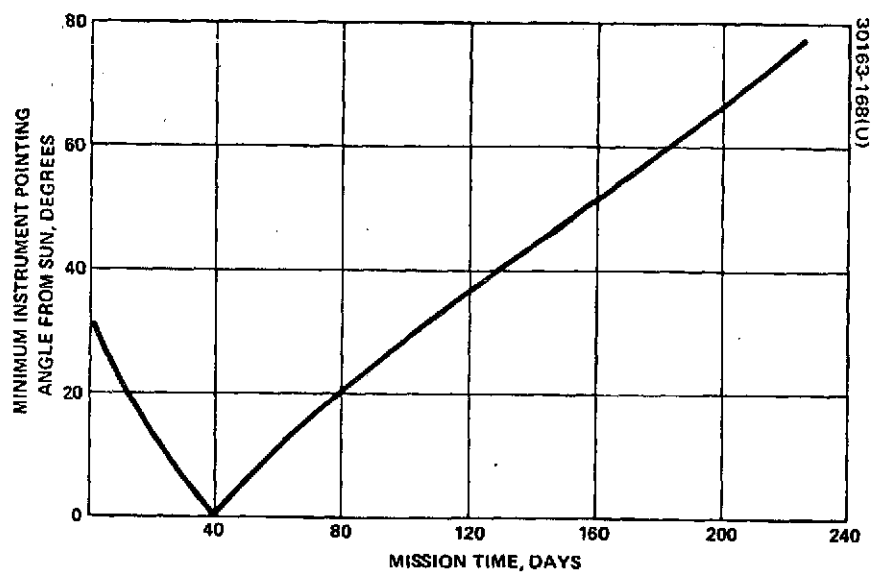


FIGURE 4-15. SUN POINTED EXPERIMENT COVERAGE -  
SPIN AXIS DIRECTED TO EARTH



TABLE 4-10. ALTERNATE DESIGN SCIENCE PERFORMANCE  
SUMMARY (SPIN AXIS DIRECTED TO EARTH)

Experiments	Percent Mission Data Coverage	Performance
Velocity oriented	100	Measurement between periapsis and 5000 km at less than 30 deg sampling angle
Sun oriented	100	Measurement angle to sun may be as high as 80 deg
Earth pointed	When applicable	Satisfactory if no maneuver to break downlink
Planet oriented	Partial	<p>Measurement of all northern latitudes restricted to certain times in mission. Increased measurement distances at most times.</p> <p>Altimeter coverage of all latitudes effective less than 35 percent of mission with 45 deg elevation boresight freedom</p>

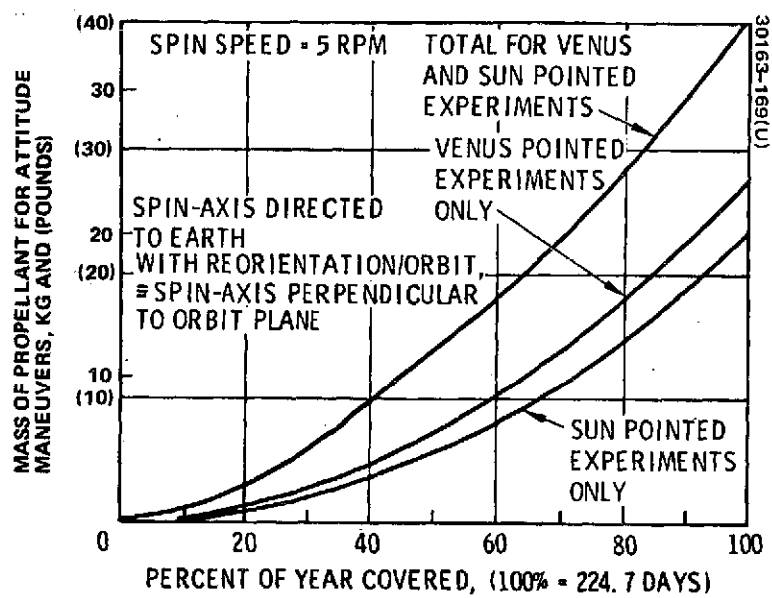


FIGURE 4-16. PROPELLANT REQUIRED FOR EXPERIMENT ORIENTED ATTITUDE MANEUVERS

TABLE 4-11. ORBITER SPACECRAFT MECHANIZATION/SYSTEM  
DESIGN COMPARISONS

Affected Area	Change From Baseline to Spin Axis Directed to Earth	
	Pro	Con
Power subsystem	Conscan earth reference (additional attitude reference)	Add solar cells front and back
Thermal control subsystem		Increased louver areas; possible need for heat pipes
Attitude control		Greater propellant requirement +2.7 kg (6 lbs) for transit +11.3 to 18.2 kg (25 to 40 lb) if reorient for science in orbit
Spacecraft structure subsystem		+15.9 kg (35 lb)
Adapter		+11.8 kg (26 lb)
Communication subsystem	Delete motor bearing assem- bly and electronics	
Science		Reduced coverage if not allowed to reorient
Mission operations		Break rf downlink if reorient for science every orbit
Overall mass		+43.1 kg (95 lb) (not including fuel for reorientation)

The chief advantage of pointing the spin axis towards earth would be the increased reliability and decreased cost of the fixed antenna relative to the despun antenna of the baseline. However, with the experience that Hughes has acquired with despun antennas on TACSAT, ATS, Intelsat IV and Anik, it is felt that acceptable levels of cost and reliability can be attained with a mechanically despun antenna.

Except for the removal of the mass consideration, all of the conclusions reached for the Thor/Delta version apply to Atlas/Centaur. It is true that now it is feasible to consider the third option, that of periodic reorientation to the orbit normal and back to earth pointing since the fuel expenditure is not consequential. However, the periodic interruption of downlink communication is still highly undesirable and may even be unacceptable. Thus, the recommendation is here made that the baseline spin axis orientation be retained even for the Atlas/Centaur version.

#### 1978 Orbiter Transit Trajectory Selection (MS25)

The considerations influencing selection of the interplanetary transit trajectory fall into two broad categories; those involving the spacecraft and operations and those involving science coverage. In general, the impact of spacecraft considerations can be expressed in terms of useful orbited mass; it happens that neither spacecraft cost nor mission operations are materially affected by the choice among the reasonable alternatives for the interplanetary transit trajectory. The performance tradeoff for Thor/Delta launch spacecraft during the 1978 launch opportunity is unusual in that the useful spacecraft mass is nearly equal for the Type I and Type II interplanetary transit trajectories. Science considerations, therefore, play a determining role in the transit trajectory selection.

The spacecraft Venus orbit is presumed to have a 24 h period, a 150 km periapsis altitude, and a 90 deg inclination to the ecliptic. These characteristics of the baseline orbit are derived in Study Task MS 4; the desirability of the 90 deg inclination for science coverage is discussed herein. The spacecraft spin axis is normal to the ecliptic plane with a despun earth pointing antenna (Study Task EX12). Either a Type I or Type II interplanetary transit trajectory can be utilized and the periapsis of the spacecraft orbiter on Venus can be in either the northern or southern hemisphere. The options that are available from the selected transit trajectories (Study Task MS 3) are tabulated in Table 4-12. The variations in ecliptic latitude and initial ecliptic longitude are due to variations in the transit trajectory throughout the 10 day launch window. The Type I trajectory with the south periapsis has the periapsis near the pole; since this alternative is extremely undesirable from the standpoint

TABLE 4-12. POSSIBLE PERIAPSIS LOCATIONS

Trajectory	Ecliptic Latitude, deg	Ecliptic Longitude From Subsolar Point, deg
Type I	4 to 13 N	-46 to -39
	90 to 81 S	-46 to -39
Type II	21 to 31 N	-63 to -54
	55 to 45 S	-63 to -54

of science coverage only, the other three options will be considered viable. The transit trajectory selection is discussed in Study Task MS 3.

Experiments which are inherently insensitive to periapsis location are given in Table 4-13. In essence, these experiments either have no pointing requirements or pointing requirements which are easily or automatically satisfied independent of orbit geometry with respect to the planet.

There are two experiments (the neutral mass spectrometer and the ion mass spectrometer) which are required to point in the direction of the spacecraft velocity vector (within  $\pm 30$  deg) at sometime during the spacecraft spin. Coverage obtained from these experiments does depend upon their deployment and periapsis latitude (but not on initial periapsis longitude). There are two planet pointed experiments; the S-band radar altimeter is continuously oriented (electronically or mechanically) to provide altitude measurements, and the infrared radiometer makes measurements along the boresight fixed to the rotating spacecraft.

The instruments are mounted as shown in Figure 4-17. Pointing requirements for the sun pointed experiment are automatically satisfied because the spin axis is held normal to the ecliptic plane. The angles  $\theta_1$  and  $\theta_2$  are optimized for each of the alternatives in periapsis location.

The coverage obtained with the velocity pointed experiments is shown in Figure 4-18 for each of the transit trajectory alternatives. An optimum experiment orientation was selected for each of the transit

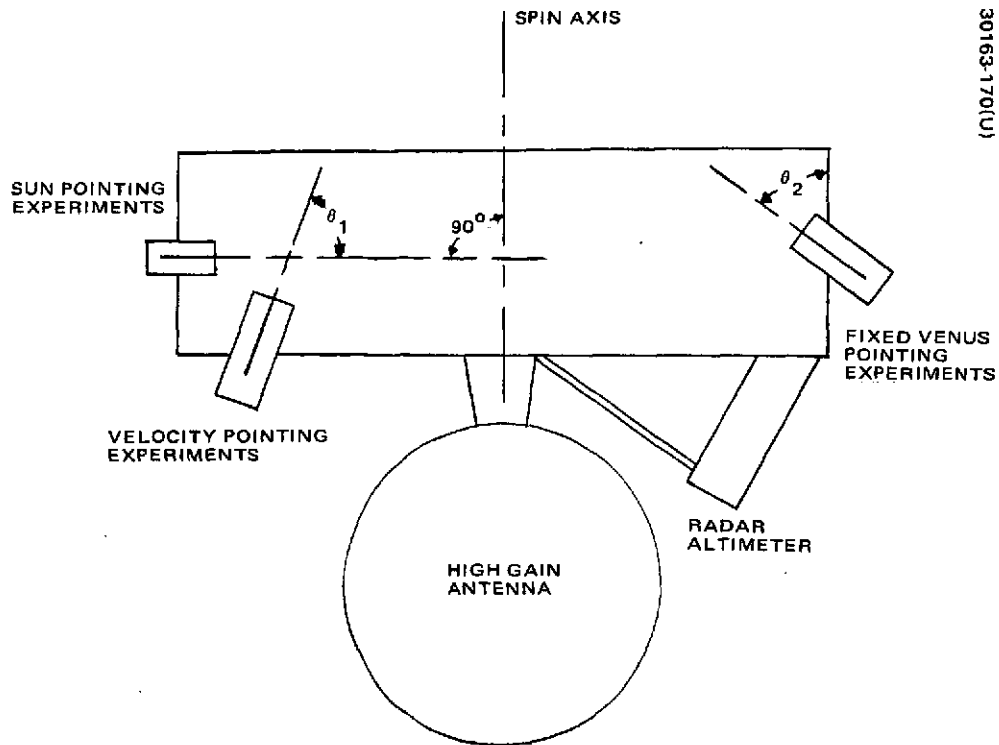


FIGURE 4-17. SCIENCE DEPLOYMENT

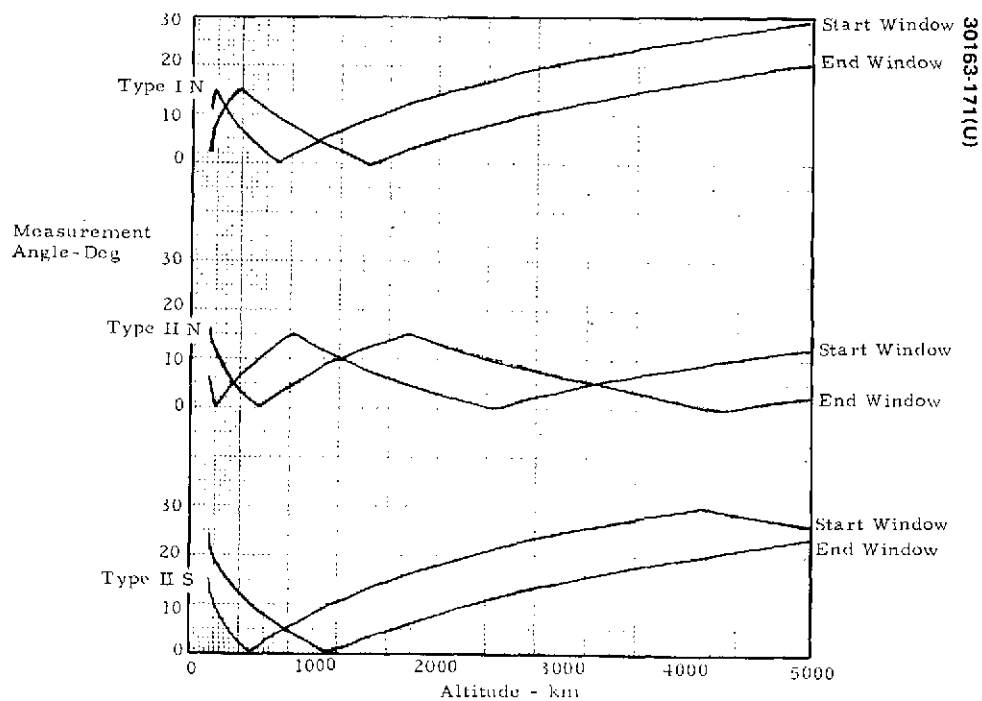


FIGURE 4-18. VELOCITY POINTED EXPERIMENT COVERAGE

TABLE 4-13. EXPERIMENTS INHERENTLY INSENSITIVE TO PERIAPSIS LOCATION

Experiment	Pointing Requirement
Magnetometer	Any orientation
Electron temperature probe	Not in spacecraft wake
UV spectrometer	Scans planet limb
S-band occultation	Uses communication antenna
Solar wind probe	Scans sun

trajectories; the coverage obtained varies throughout the launch window as the periapsis latitude varies. Note that in all cases the maximum measurement angle is not greater than the limiting value of 30 deg, indicating that satisfactory velocity pointing experiment coverage can be obtained for any of the transit trajectory alternatives when the orbit inclination is 90 deg to the ecliptic. The measurement angles are increased as orbit inclination is decreased; the smaller measurement angles obtained with the Type II north transit trajectory would permit orbit inclination to be reduced to about 70 deg without loss of coverage (for the other trajectory alternatives, an inclination reduction leads to loss of coverage). The tradeoffs in the altimetry coverage will be used to represent all planet pointed coverage because the coverage tradeoffs obtained with the altimeter and with an optimally pointed fixed instrument (e. g. , the IR radiometer) are essentially identical.

Science coverage considerations include not only periapsis latitude but also the initial value of periapsis longitude. The initial value of periapsis longitude is important because it represents the number of days of sunlit measurements before the spacecraft orbit passes the terminator (this

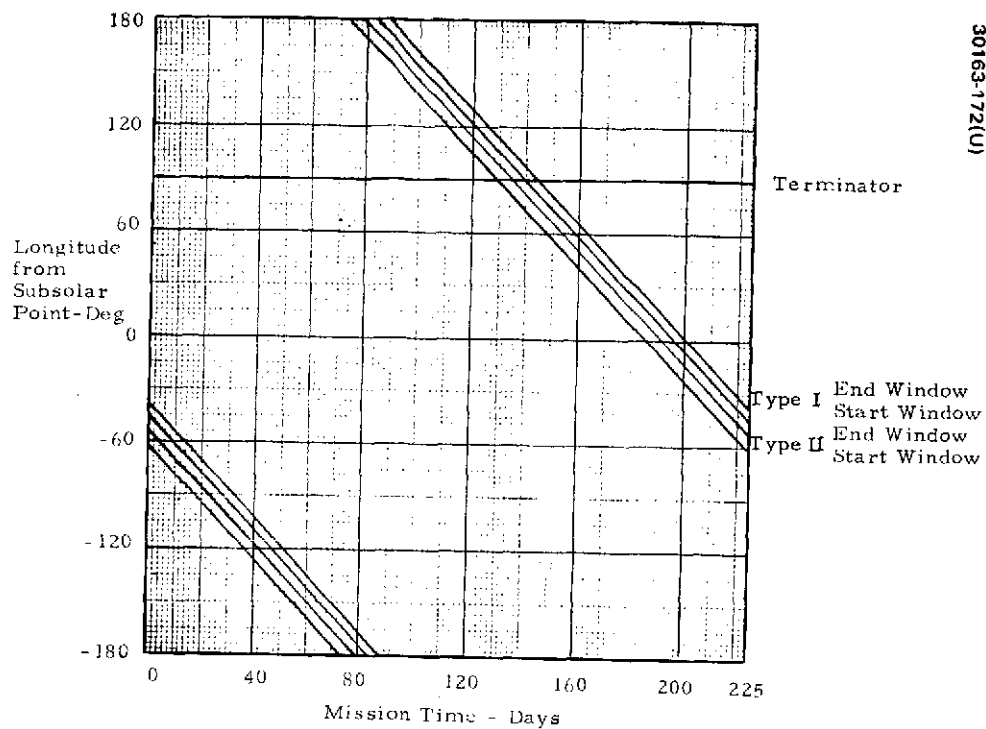


FIGURE 4-19. PERIAPSIS LONGITUDE VARIATION

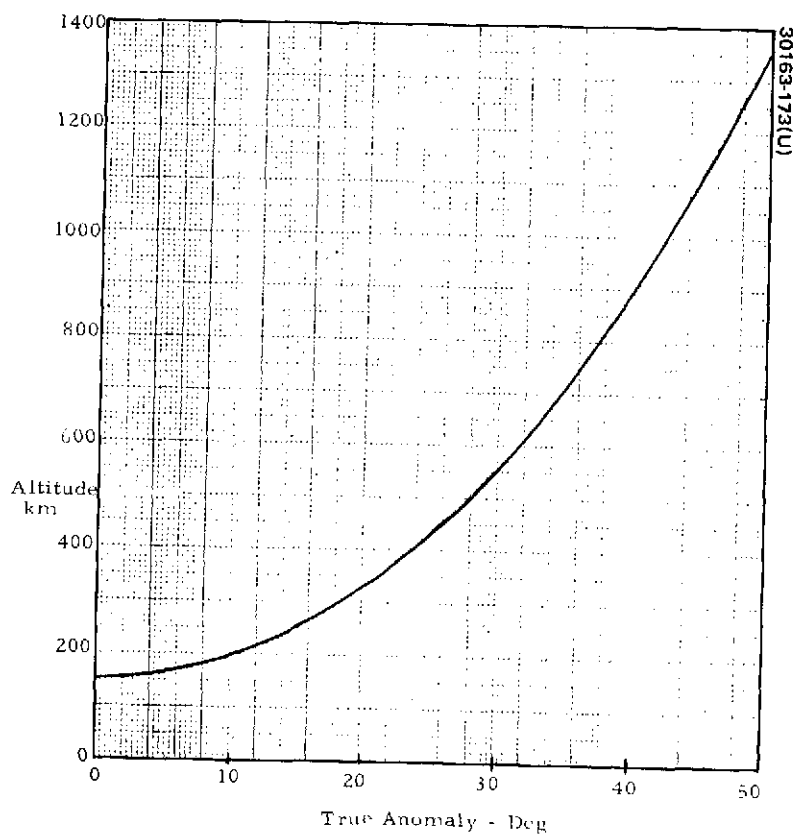


FIGURE 4-20. ALTIMETRY LATITUDE COVERAGE



movement with respect to the terminator is due to the rotation of Venus around the sun). Periapsis longitude variation throughout the mission is shown in Figure 4-19 for both Type I and Type II trajectories (north and south periapsis trajectories are the same). Variation and coverage with either trajectory time depends upon what day during the launch window the spacecraft is launched. The Type I trajectories reach the terminator from 28 to 32 days after orbit insertion versus 17 to 23 days for the Type II trajectories. Either of these alternatives appears satisfactory and the initial value of periapsis longitude is, therefore, not a determining factor in transit trajectory selection.

The coverage obtained with the altimeter is shown in Figure 4-20 (for a 90 deg inclination orbit a true anomaly variation is equivalent to a latitude variation). Based on a maximum altimetry range of 1000 km, the maximum latitude coverage band is about 84 deg. Since the slope of the curve is quite steep at this point, even a small increase in latitude coverage requires a considerable improvement in instrument performance. It therefore appears likely that complete coverage of a single hemisphere during a single mission is unlikely even if an optimum periapsis location could be obtained.

The actual altimeter coverage obtained is shown in Figure 4-21 for the three transit trajectory alternatives. For the Type I trajectory there is complete coverage of the equatorial region, but very limited coverage of the higher latitude even if the spacecraft is launched at the end of the launch window. This science coverage is considered undesirable. The Type II north periapsis trajectory provides complete coverage in the equatorial and middle latitude regions at the expense of leaving a relatively small polar cap unmapped. The Type II south trajectories provide a periapsis which gives coverage at the high latitudes but no coverage at the equator, or even in the equatorial region at the start of the mission. The area of the planet's surface which is mapped is obviously much less for the Type II south trajectory than for either of the other two alternatives. Although there will be mapping coverage in the equatorial region from earth based tracking in the time frame of this mission, the accuracy of this tracking relative to that obtained from mapping with the orbiter is debatable. In any case, equatorial mapping coverage can at worst be considered a desirable mission feature.

The judgment that the coverage obtained from the Type I trajectory is inferior to the other two alternatives is probably not controversial whereas the selection of the north or south periapsis for the Type II trajectory is more subjective. This study assumes that the coverage obtained with the Type II north trajectory is at least as desirable as that obtained with the Type II south, and this alternative has been selected as the baseline.

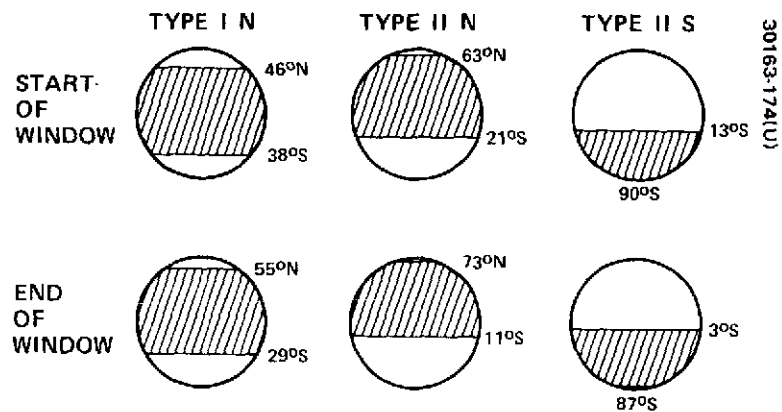


FIGURE 4-21. ALTIMETRY COVERAGE AT ALTITUDE  $\leq 1000$  KM

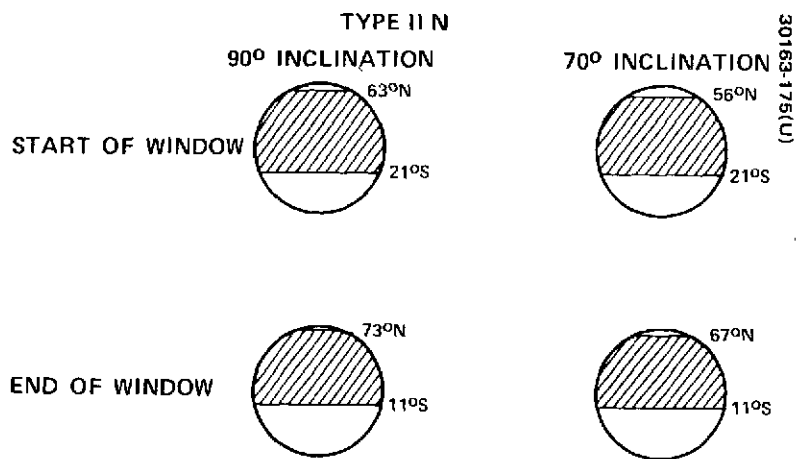


FIGURE 4-22. EFFECT OF INCLINATION ANGLE ON ALTIMETRY COVERAGE AT ALTITUDE  $\leq 1000$  KM

The effect of orbit inclination on latitude coverage is to decrease the maximum latitude covered. The degradation in latitude coverage for a 70 deg inclination is shown in Figure 4-22 for the Type II north trajectory. Since the maximum latitude covered can never be greater than the orbiting inclination, a 70 deg orbit on the Type II south trajectory would decrease high latitude coverage to 70 deg. This alternative is even less desirable than a 70 deg inclination on the Type II north trajectory because selection of the Type II south trajectories implies a sacrifice of equatorial coverage to obtain high latitude coverage. The only potential advantage of a 70 deg angle inclination orbit is that the latitude of periapsis can be moved about 7 to 8 days further from the terminator than for the 90 deg inclination, but this is not a significant consideration because the periapsis location with respect to the terminator is satisfactory. It may also be noted that both velocity pointed instrument measurement angle and orbit maintenance propellant requirements (due to spin axis/orbit geometry considerations) are degraded as the orbit inclination deviates from 90 deg. Since orbit inclinations other than 90 deg have considerable disadvantages and no true benefit, the selection of a 90 deg inclination for the baseline orbit is optimum.

Spacecraft and operational considerations provide a small advantage to the Type II north transit trajectory in comparison to the other alternatives. The spacecraft orbit at Venus which is obtained utilizing a Type I transit trajectory has science coverage which is inferior to that obtained utilizing the Type II transit trajectory. A case can be made that the science coverage obtained with the Type II north periapsis is at least equal to that obtained with the south periapsis. For these reasons the Type II north periapsis has been selected as the baseline for the purposes of this study. It should be noted, however, that spacecraft modifications required to utilize the south periapsis as the baseline are very minor. The same retromotor can be used and the hydrazine tankage provided on the baseline is adequate for use with the south periapsis alternative. The only spacecraft design change required is a small variation on the mounting angles of the velocity pointed and planet pointed science experiments. This reorientation is not difficult.

### Payload Design Integration (EX2)

The purpose of this task was to identify and resolve payload accommodation problems by understanding the instrument and science requirements and relating them to integration requirements.

Descriptions of all of the orbiter instruments and their requirements are contained in the Experiment Engineering Data Book, which is the principal output of EX2, and was discussed in subsection 3.3, with an example instrument writeup.

TABLE 4-14. SPECIAL EXPERIMENT REQUIREMENTS IMPACTING THOR/DELTA ORBITER DESIGN

Experiment	Special Requirement	Implementation*
Magnetometer	5V background	1.1 m (42 in.) deployed boom, magnetic control
Electron temperature probe	Negative polarity solar panel	Coating all solar panel surfaces with insulation material
Neutral mass spectrometer	Velocity pointing, low spin speed	Offset from spin axis for correct periapsis pointing, 5 rpm spin
Ion mass spectrometer	Velocity pointing, low spin speed	Offset from spin axis for correct periapsis pointing, 5 rpm spin
UV spectrometer	Scan Venus limb, low spin speed	90° to spin axis 5 rpm spin
IR radiometer	Scan Venus disk, low spin speed	Offset from spin axis for correct planet pointing, 5 rpm spin
RF altimeter	Pointing to local vertical, low spin speed	Tight attitude control system, 5 rpm spin
RF occultation	None	(Uses communications system)

\*Polar orbit, spin axis perpendicular to ecliptic.

Table 4-14 summarizes the special experiment requirements which impacted the orbiter design for Thor/Delta. Magnetic control problems associated with a 1.1 m (42 in.) magnetometer boom, have led to a decision to go to a 4.6 m (15 ft) boom for Atlas/Centaur (subsection 3.3).

The electron temperature probe is sensitive to the charge potential of the spacecraft structure and would prefer to have a negative polarity solar panel to prevent the large negative charge that would develop as ionospheric electrons were attracted to the positive spacecraft potential produced by solar photon induced photo emission from the surface.

Implementation of a negative polarity solar panel, with minimum impact on existing OSO designs, has been investigated. One method of accomplishing this is to use a dc/dc converter to invert the polarity of the solar panel power source. For the orbiter this would entail two 3.6 kg (8lb) inverters (redundant) plus 0.45 kg (1lb) of switching circuitry, resulting in a total electronics mass increase of approximately 7.7 kg (17 lb). The solar panel size would have to be increased to compensate for the inverter losses. Assuming 90 percent power efficiency, solar cell and substrate mass would increase by approximately 1.4 kg (3 lb). Therefore, total spacecraft mass would increase by 9.1 kg (20 lb).

Another possible method is to maintain the present configuration but merely connect the positive (instead of the negative) terminal of the solar panel and power bus to structure ground. This means that signal returns, which are connected to the negative power return at a single point, are no longer sunk to the structure. They would float with respect to the structure. This would result in much greater noise susceptibility of telemetry, command, control and other low level signals. It would also introduce a dangerous failure mode. Electrical contact with structure of any one of the very large number of signal returns would result in a power short circuit.

To implement the above configuration would also require a modification to the transmitter power amplifiers. Only NPN high frequency power amplifiers are available for S-band and they require a positive polarity power source. In addition, negative power return and signal return cannot be isolated from each other and structure. They must be connected to structure in the transmitter itself to obtain a suitable ground plane. Therefore, if the positive terminal of the primary power source is connected to structure, an isolating dc/dc converter must be provided in each transmitter.

A meeting was held on 9 May at Hughes with L. H. Brace of Goddard (electron temperature probe co-investigator) to discuss alternate methods of preventing undesirable spacecraft charge potentials. Although his

preference is for a negative polarity solar panel, he stated that coating of all exposed external power wiring with a suitable insulation material (primarily solar cell interconnects) would restrict structure charging to very low levels and would be a satisfactory solution. This technique was utilized successfully on the ISIS spacecraft.

Connecting the positive terminal of the solar panel to structure entails a number of difficult spacecraft design changes and compromises. The most satisfactory solution at this time is to coat all solar panel surfaces not protected by cover glass with an insulation material. All external exposed power harnesses must also be coated.

The low spin rate of 5 rpm that many orbiter instruments desire is achievable at the cost of added complexity for the attitude control system, which must make attitude corrections more often. The pointing requirements of the rf altimeter also put a constraint on the attitude control system operation.

The S-band occultation experiment in the Thor/Delta payload posed no particular problem; however, the addition of X-band occultation in the Atlas/Centaur has put a strong requirement for two-axis pointing of the communication antenna in order to track the beam deflection by the atmosphere as occultation occurs. This is discussed in the subsection that immediately follows.

#### Orbiter Radio Science Impact on Communication Subsystems (CM19)

This task was originally intended to study the impact on the spacecraft of a Pioneer Venus radio science package that was fully integrated with the telecommunications subsystems. Following redirection by Ames Research Center the integrated concept was discarded. Under the new requirements the radar altimeter was not to be integrated with the spacecraft telecommunications subsystems but was to be a dedicated (bolt-on) instrument with its own mass and power budget. The S-band occultation experiment was part of the nominal payload with no mass and power budget above that required for spacecraft telecommunications. The dual frequency occultation experiment was placed in the other candidate instrument category and the second frequency was defined as X-band. The microwave radiometer was deleted as a payload item. The bistatic radar was delegated to a possible increased capability of the altimeter. This study task addresses the radio science package as redefined and outlined above. Only those portions of the package that impact the telecommunications subsystems (i. e., the S- and X-band occultation experiments) are discussed in detail.

Since the S-band occultation experiment has by definition no mass and power allocation above that needed for telecommunications, it also has by definition no impact on spacecraft telecommunications design. However, with or without the second (X-band) frequency, a two-dimensional steering capability to track the virtual earth as the spacecraft enters and exits occultation will increase the duration the signal is received on earth and thus improve the experiment. This type of capability is included on the Mariner Venus-Mercury (MVM) flyby spacecraft.

For the dual frequency occultation experiment, provision must be made for providing an X-band signal which is coherent with the S-band signal and an X-band antenna capability. The two-dimensional antenna tracking capability is more important at X-band because of the narrower antenna beamwidth.

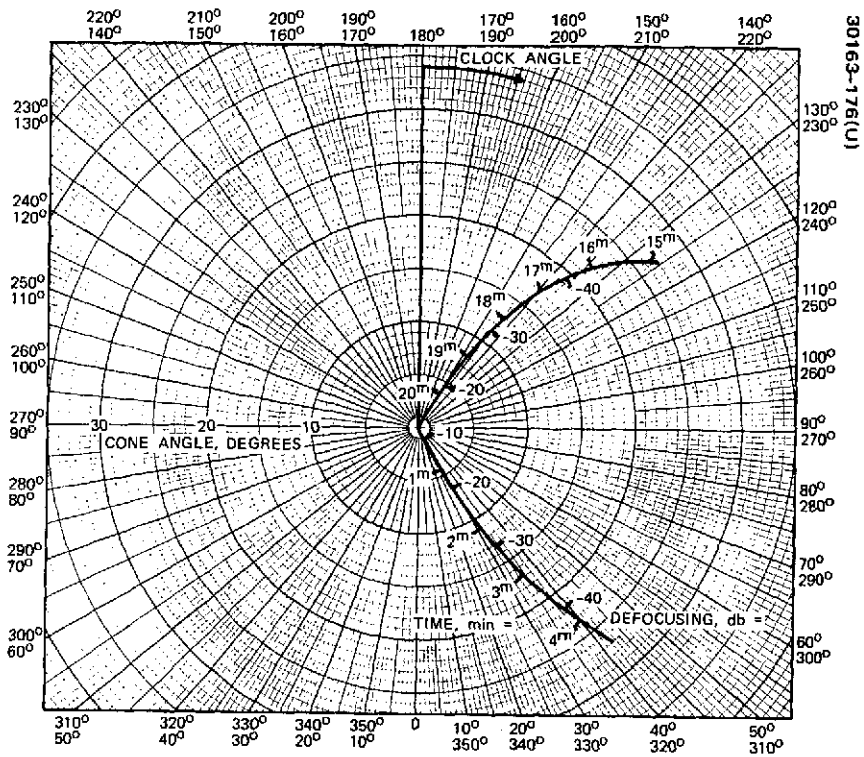
With the HS-507 baseline mechanically despun antenna the addition of an X-band capability and two-dimensional steering is relatively easy to accomplish. An X-band transmitter of the MVM type would be added. The X-band signal would be routed to the antenna feed via one channel of a dual channel rotary joint. The feed would be modified to an X-band horn surrounded by an S-band helix (with the net gain at S-band reduced slightly by 0.2 dB). Steering in azimuth would be provided by despun bias whereas steering in elevation would be provided by an elevation gimbal on the high gain antenna.

The Pioneer Venus orbiter NASA/ESRO JWG report (Reference 2-6) stated two requirements for the occultation experiment as:

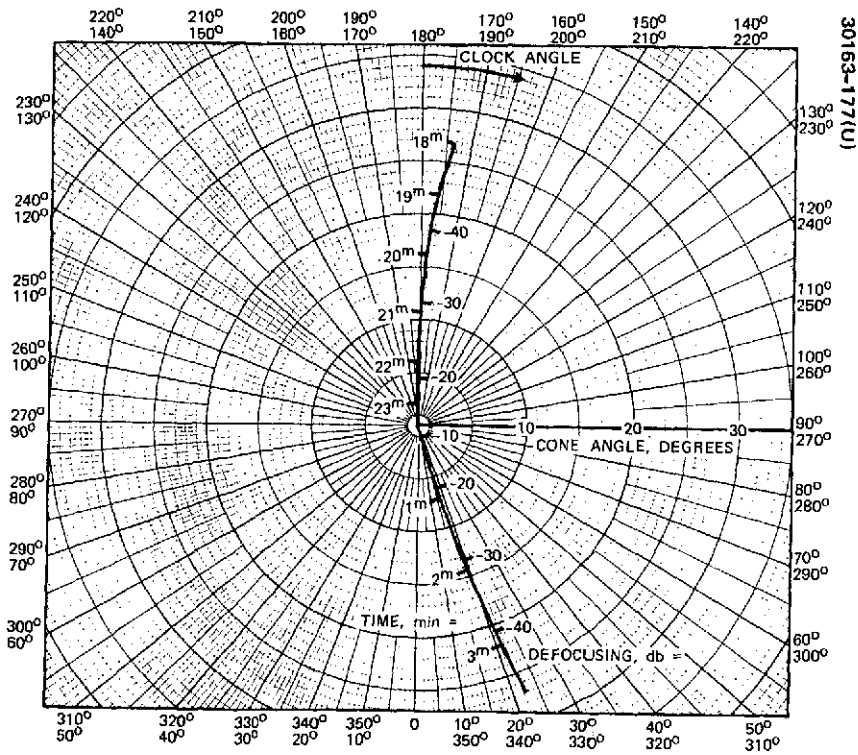
- 1) The orbiter high-gain antenna must be able to follow the direction of the radio beam when it is refracted in the atmosphere of Venus.
- 2) A second frequency (X-band) coherent with the S-band frequency must be provided on the downlink.

While neither of these was explicitly required by the Pioneer Venus science payload listing, the dual frequency occultation being "another candidate instrument" and the two-dimensional steering of the antenna not being mentioned, these two requirements formed the basis of this study.

A study of the expected beam track during Pioneer Venus occultations has been made at JPL, with orbital data from Hughes. Figure 4-23 shows plots of the expected beam track; i. e., the direction to the image of the earth as seen from the orbiting spacecraft for orbits at insertion and 35 days after. The cone angle is measured from the spacecraft earth



a) AT ORBIT INSERTION



b) 35 DAYS AFTER ORBIT INSERTION

FIGURE 4-23. EXPECTED BEAM TRACK DURING OCCULTATION



vector. Zero clock angle is defined in the usual manner with reference to Canopus. The cone angle excursion of the beam can be bounded by  $\sim 20$  deg assuming that refractive defocusing of greater than 40 dB makes tracking unnecessary beyond this bound. Thus, a limit of  $\pm 20$  deg on the high gain antenna elevation and azimuth steering requirement for the occultation experiment can be inferred. It should be noted here that if an elevation steering capability is added for radio science, the required range may well be determined by spacecraft operational considerations (Study Task CM 12).

In Reference 2-6 gravitational measurements during an extended mission period are recommended. The requirements listed therein for this extended mission period include:

- 1) Availability of S- and X-band communication links for extensive tracking before and after sun occultation.
- 2) No active control of the orbit, and no attitude control, thus allowing the periapsis to rise naturally above 500 km, and stabilizing the spacecraft by increasing the spin rate.

The spin rate obtainable during this period will be bounded by the upper spin rate limit ( $\sim 35$  rpm) of the despun control electronics which is selected based on spacecraft stability requirements for maneuvers during the transit and orbit insertion phases. At this spin rate, solar torque precession will accumulate to move the antenna beam off the earth in a period that is short compared with the extended mission of one Venus sidereal rotation period (243 days). A spin rate on the order of 100 rpm or a program of solar torque balancing would be required to allow operation for 243 days without attitude corrections. Thus, requirements (1) and (2) above are mutually exclusive with the current spacecraft design. A decision must be made as to whether to modify the spacecraft design to satisfy these extended mission requirements if the recommendations of Reference 2-6 are to be implemented.

#### Payload Tradeoff Analysis (EX1)

Early in the study, three of the five other candidate instruments for the orbiter were deleted; and one, the solar wind probe, was moved up to the nominal instruments. This left only the thermal/suprathermal particle detector, which was deleted in the April Atlas/Centaur payload. Because of uncertainties in the orbiter payload, work on this study task was not begun until receipt of the final Atlas/Centaur payload model.

There are now three other candidate instruments to be considered; the ac electric field detector, the microwave radiometer, and the spin-scan photometer. (The microwave radiometer had been part of the nominal payload for the original proposal, and the spin scan photometer another candidate instrument at that time.) Characteristics of these instruments are given in

Table 4-15. Both the microwave radiometer and the spin scan photometer would have a major impact on the system because of their large periapsis data storage requirements.

#### AC Electric Field Detector

The electric field instrument will measure plasma waves originating from the solar wind/ionosphere interaction. It is required to operate during the complete orbit and during cruise.

The instrument consists of an electronic unit to be mounted on the equipment platform and an antenna system that must be positioned remote from the spacecraft to reduce the spacecraft generated ac signals at the sensor. The frequency response of the sensor is from approximately 20 Hz through to several Mhz. It will operate with or without spacecraft spin.

The sensor usually consists of a lightweight crossed dipole array, and suitable deployment distances are from 90 to 120 cm from the outer edge of the solar array. The total mass of such a system is estimated to be less than 1.35 kg and a study of accommodating this boom shows that the existing bus design would not be heavily impacted. If however, as dictated by the requirements this experiment is required to operate during the cruise phase, either a boom retraction system is required, or the deployed boom will have to be strengthened to withstand the motor firing shock at orbit insertion. It is estimated that the boom mass will increase from 1.8 to 2.3 kg to withstand this force.

TABLE 4-15. ORBITER - OTHER CANDIDATE INSTRUMENTS

Instrument	Mass kg (lb)	Volume cm <sup>3</sup> (in. <sup>3</sup> )	Power Watts	Data Rate bps	
AC electric field detector	2.7 (5.75)	3392 (207)	3.6	cruise > 4000 km periapsis	2,25 195,000 5,600
Microwave radiometer	13.1 (28.72)	11310 (690)	18.0	periapsis	250,000
Spin-scan photometer	10.4 (23.0)	9405 (575)	18.0	> 4000 km periapsis	3,600,000 378,000

The above parameters include the tolerances of: +15% mass  
+15% volume  
+20% power

The instrument mass, volume and power requirements given in Table 4-15 along with the boom mass of 2.3 kg could be integrated into the present orbiter design without any large impact.

The periapsis telemetry requirement of 5,600 bits can be accommodated in the existing data storage unit. The present real-time telemetry capability would also accommodate the total orbital requirements of this instrument.

#### Microwave Radiometer

The microwave radiometer measures the thermal emission from the planet surface with a resolution of  $\pm 1^\circ$  K. Operation is during the periapsis period when the orbiter is within 2000 km of the planet. Data collection during this period is 250,000 bits.

The instrument consists of an electronic unit and a large parabolic dish antenna. In the 13 mm to 19 mm wavelength, (Mariner II) the dish will be 48.5 cm in diameter. Planet pointing is required during the periapsis period. Spacecraft spin is required, preferably at some low rate near 5 rpm.

The accommodation of a parabolic antenna 48 cm in diameter and angled to the spin axis for planet scanning during periapsis could be accommodated providing the antenna weight did not exceed 1 kg. Further study might show that the antenna could be combined with that of the altimeter instrument of the nominal payload.

Table 4-15 shows that this instrument and the spin scan photometer have demanding mass, volume and power requirements. The telemetry requirements for both during the periapsis period would require a larger data storage system. The present data storage design is sized for  $10^6$  bits. A time sharing system could be used or, if this is not suitable, a larger storage is required. A larger storage requirement would probably result in magnetic tape recorders rather than the present core memory. Other than additional power, tape recorders are not expected to have a large impact on the design.

#### Spin Scan Photometer

The spin scan photometer is one unit comprising the electronics and the sensor. This instrument would map the upper clouds of Venus in the UV, visible and IR bands. The sensor is required to be planet pointing mainly during the periapsis period, however, measurements are also required during that time in the orbit that the planet fills only a small part of the sensor. The field of view is approximately  $1^\circ$  conical, and is mechanized to allow a  $20^\circ$  movement about that axis orthogonal to the spin.

The telemetry requirement during one periapsis pass is  $38 \times 10^5$  bits. During the remainder of the orbit, telemetry requirements are approximately  $3.6 \times 10^5$  bits.

#### Orbiter Spacecraft Experiment Interface Specification (SP4)

This specification will define the spacecraft side of the interfaces with the scientific experiments. It will contain all pertinent requirements in sufficient detail necessary for instrument development. Detail instrument interfaces will be provided by NASA /ARC.

A draft of the experiment interface specification document appears in Volume 16.

#### 4.4 SCIENCE PAYLOAD ACCOMMODATIONS

The problems associated with integrating all of the orbiter nominal science payload instruments together compatibly will be discussed in this section, with the primary focus on the Atlas/Centaur baseline (April 1973). The final Atlas/Centaur baseline defined in the June RFP was not available at the time of completion of this final report; thus these accommodation discussions are interim in nature. Accommodation of the final Atlas/Centaur payload will be discussed in the technical proposal.

At the mid-term review, the major emphasis was on accommodation of the Thor/Delta payload. For completeness and continuity with earlier studies the Thor/Delta configuration will also be shown here, although the discussion of instrument accommodation will be in terms of Atlas/Centaur.

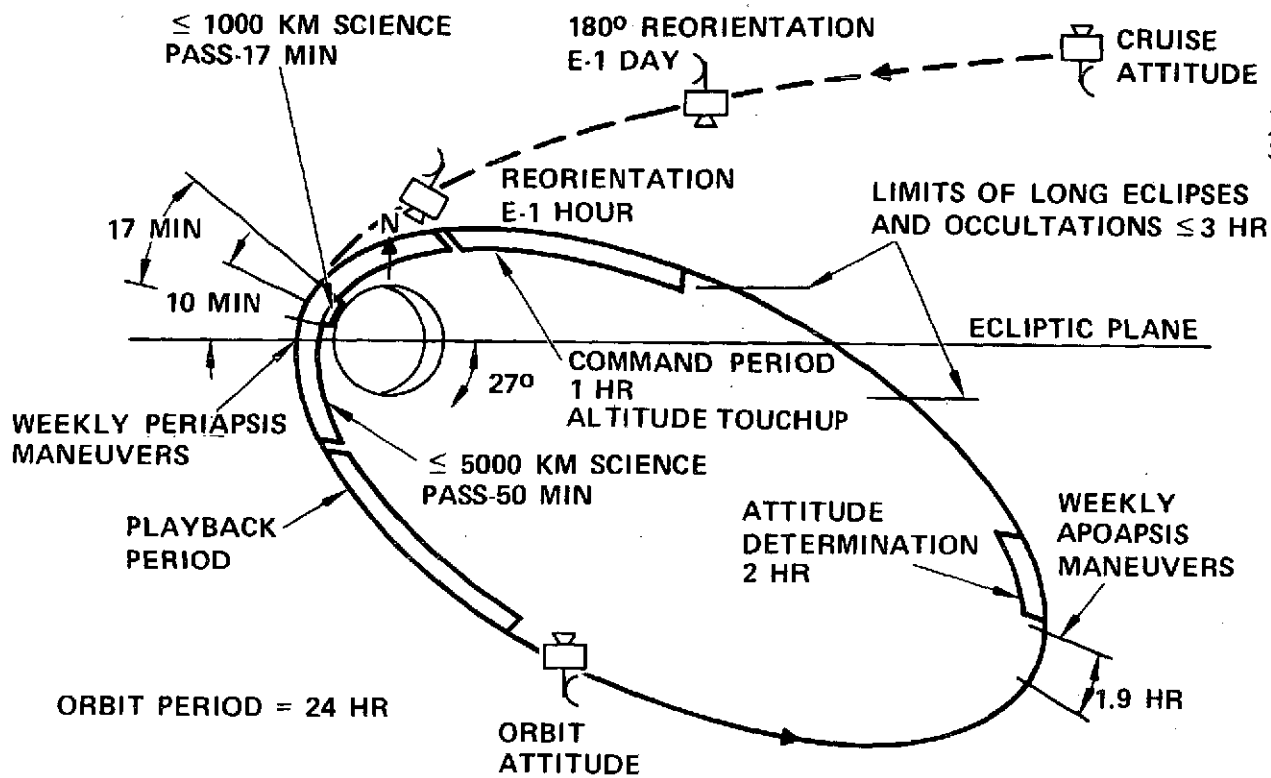
Before considering the specific accommodation of science instruments, it is of interest to review the significant system decisions made as a result of experiment tradeoff studies. These include 1) for best observing conditions from the spacecraft the spin axis should be normal to the ecliptic plane, 2) for best planetary coverage, a Type II transit trajectory to permit periapsis location in the most preferred mid-latitude region is desired, 3) a long magnetometer boom (4.4 m) is the most cost effective solution to magnetic control, and 4) an elevation drive is required on the high gain antenna to meet  $\pm 20$  deg requirements for the S band and X band occultation experiment. For the relaxed  $\pm 10$  deg requirements, a separate X band horn with no elevation drive appears to be the most cost effective solution.

The nominal science payload for the Atlas/Centaur orbiter was presented in Table 4-4. Typical orbital operations are shown in Figure 4-24 (which would generally hold for either a north or south latitude periapsis). Operating characteristics for the science instruments are given in Table 4-16. Several instruments desire a spin rate as low as 5 rpm. Nominal experiment data sampling requirements are given in Table 4-17 as specified by NASA/ARC. Orbiter data formats developed for the high data rate periapsis passage are shown in Figure 4-25, and Table 4-18 compares implemented data rates with required rates. A data storage of  $10^6$  bits is provided to accommodate the periapsis data rate, which is in excess of the downlink capability, and to handle occultation periods.

The orbiter has a command capability of 192 pulse and 12 magnitude commands. Of these 43 pulse and 1 magnitude commands have been allocated to the science experiments. Sufficient spares remain should more be required.

The system provides the capability to have the magnetometer and solar wind analyzer on during cruise phases except during trajectory correction maneuvers (periods of 1 to 2 hours) and battery charge (12 to 24 hour) periods.

In Venus orbit, the magnetometer and uv spectrometer are on continuously. The radar altimeter is on only for a 20 min period ( $\pm 10$  min) about periapsis. All of the other instruments, except the solar wind analyzer,



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FIGURE 4-24. ORBITAL OPERATIONS

TABLE 4-16. OPERATING DETAILS FOR ORBITER INSTRUMENTS

Instrument	Operating Altitude, km	Spin, rpm	Squibs	Commands*
Magnetometer	Cruise and complete orbit	Any	—	4
Solar wind analyzer	Cruise and >4000	Any	—	4
Electron temperature probe	<4000	Any	—	5
Neutral mass spectrometer	<4000	~5 rpm	1	7
Ion mass spectrometer	<4000	~5 rpm	1	4
UV spectrometer	Complete orbit	Any	—	4
IR radiometer	<3000	~5 rpm	—	4
X-band occultation	Occultation only	—	—	4
Radar altimeter	<1000	~5 rpm	—	5 + mag. command

\* Does not include ON/OFF commands

TABLE 4-17. ORBITER NOMINAL EXPERIMENT DATA REQUIREMENTS

Instrument	Data Description	Analog or Digital	Data Acquisition Range*, km	Approximate Acquisition Interval, min*	Typical Minimum Data Requirements			
					Bits per Measurement	Total Bits per Pass	Data Rate bps**	Analog Words
Magnetometer	Science Housekeeping	D A, D	Cruise		32	—	3	
			Orbit >4000	1400	32	252,000	3	3
			Orbit <4000	42	32	80,000	32	
Solar wind analyzer	Science Housekeeping	D A, D	Cruise		32	—	3	
			Orbit >4000	1400	32	252,000	3	4
			Orbit <4000	—	—	0	0	
Electron temperature probe	Science Housekeeping	D A, D	Orbit >4000	—	—	0	0	
			Orbit <4000	42	24	60,000	24	2
Neutral mass spectrometer	Science Housekeeping	D A, D	Orbit >4000	—	—	0	0	
			Orbit 500<r<4000	30	—	45,000	25	3
			Orbit <500	12	—	72,000	100	
Ion mass spectrometer	Science Housekeeping	D A, D	Orbit >4000	—	—	0	0	
			Orbit 500<r<4000	30	—	45,000	25	2
			Orbit <500	12	—	72,000	100	
UV spectrometer	Science Housekeeping	D A, D	Orbit >4000	1400	—	144,000	1.67	
			Orbit <4000	42	—	85,000	34	2
IR radiometer	Science Housekeeping	D A, D	Orbit >3000	—	—	0	—	
			Orbit <3000	30	—	180,000	100	3
Radar altimeter	Science Housekeeping	D A, D	Orbit >1000	—	—	0	0	
			Orbit <1000	16	—	96,000	50	3

\* Data acquisition ranges shown are typical; will vary with selection of orbital geometry.

\*\* Data rates shown are for periods of acquisition indicated; not averages over entire orbit; include both science and digital housekeeping data.



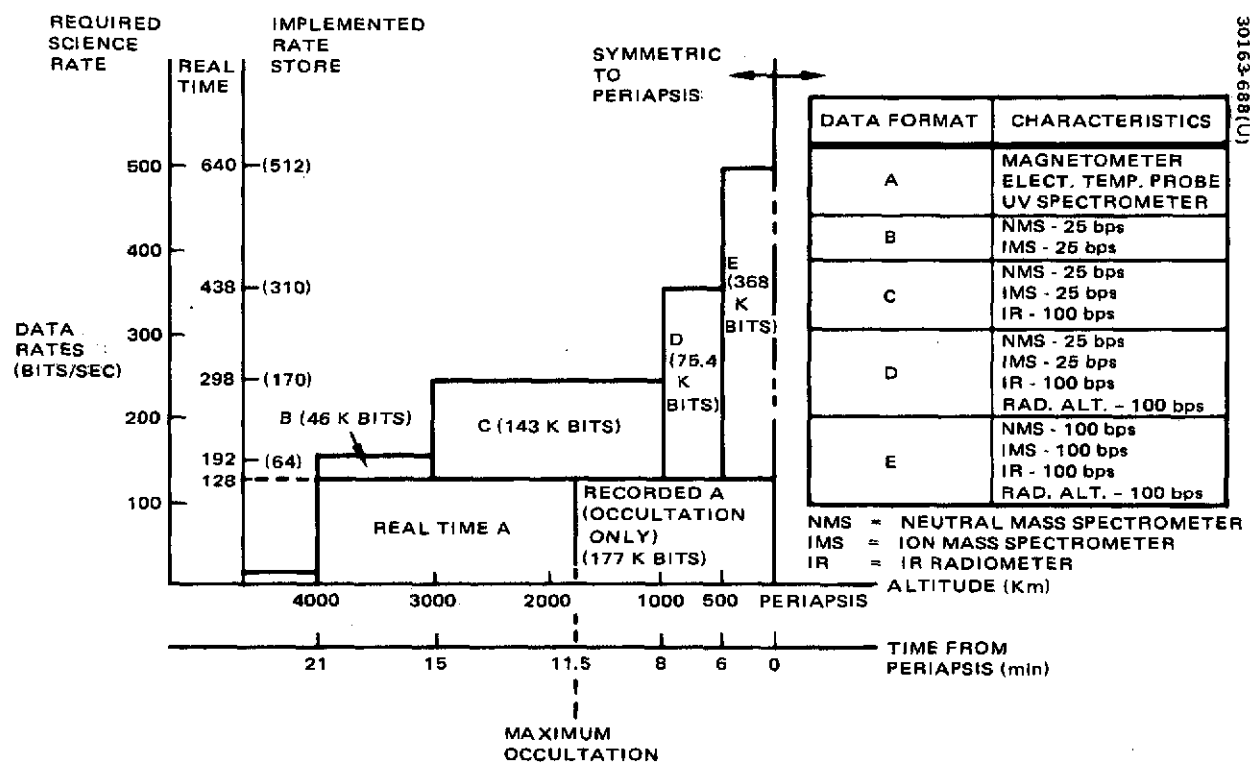


FIGURE 4-25. ORBITER DATA FORMATS

TABLE 4-18. PERLAPSIS DATA FORMATS

Science Instrument \ Format Clock Rate Duration	A 128 bps 42 min	Science Instrument \ Format Clock Rate Duration	B 64 bps 12 min	C 170 bps 14 min	D 310 bps 4 min	E 512 bps 12 min
Magnetometer	32 / 33.7	Neutral mass spectrometer	25 / 26.2	25 / 25	25 / 27.2	100 / 105
Electron temperature probe	24 / 26.2	Ion mass spectrometer	25 / 26.2	25 / 25	25 / 27.2	100 / 105
UV spectrometer	34 / 37.5	IR radiometer		100 / 100	100 / 100	100 / 105
-	Required rate bps / Actual rate bps	Radar altimeter			100 / 100	100 / 105

are on for a 60 min period ( $\pm 30$  min) about periapsis. The solar wind analyzer is on for the remaining 23 hour portion of the orbit. The S and X band occultation experiment operates during periapsis occultations which occur during the first few months after orbit injection.

The mass, volume, and power allocated to the orbiter payload are 45.4 kg (100 lb),  $58,370 \text{ cm}^3$  ( $3490 \text{ in}^3$ ), and 107.4 W. This includes a 15 percent increase in mass and volume and a 20 percent increase in power over the nominal payload values. These numbers represent the upper limit on the tolerances placed on the nominal values, and were adopted to provide NASA/ARC with some flexibility for payload changes with low cost risk.

The Atlas/Centaur spacecraft gimballed antenna design is shown in Figure 4-26, and the equipment shelf layout in Figure 4-27. All instruments are accommodated on the shelf, which is located at the upper end of the structure (similar to the probe bus), with the exception of the sensors of the magnetometer and electron temperature probe, and the antennas of the radar altimeter and the rf occultation experiment. Mechanical integration details of individual instruments are given in Table 4-19.

The Thor/Delta orbiter nominal payload was presented in Table 4-2. Figure 4-28 shows a plan view of the spacecraft baseline design, and Figure 4-29 is a pictorial view, showing the fields of view. Layout of the science instruments on the spacecraft equipment shelf is shown in Figure 4-30. The same basic instruments were carried as for the Atlas/Centaur, but the rf occultation experiment was single frequency rather than dual frequency.

Layout on the equipment shelf provides flexibility for instrument viewing from the spacecraft either perpendicular to the spin axis or along the spin axis. The areas around the spacecraft above the solar cells are kept clear of other functions as much as possible to allow for this flexibility.

Accommodation of each of the Atlas/Centaur science instruments is discussed in more detail in the following paragraphs.

### Magnetometer

The magnetometer sensor is mounted on a boom to minimize magnetic control costs. The boom extends a distance of 4.4 m (14.5 ft) from the edge of the spacecraft at 90 deg to the spin axis. The boom is a three-section, articulated arm structure which is initially stowed over and above the equipment shelf. Once extended, it is nonretractable. It is configured to maintain the three axes of the magnetometer sensor to within 1 deg of the X, Y, and Z axes of the spacecraft when deployed. The electronics unit of the magnetometer is positioned on the equipment shelf in close proximity to the boom. This technique and boom size eliminates costly magnetic control requirements on the spacecraft and equipment assuming a 0.8Y (demagnetized) field at the sensor is satisfactory.

4-54

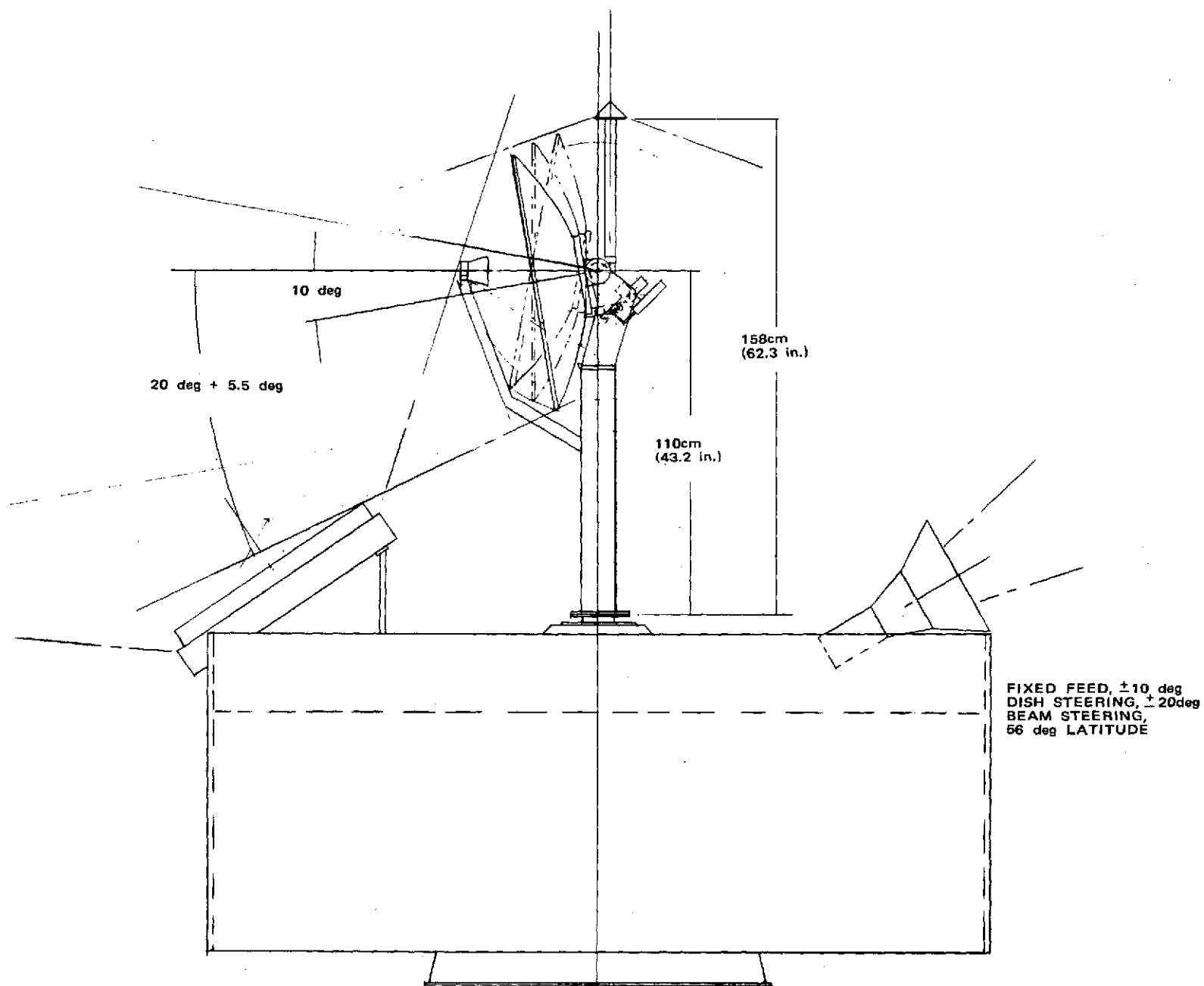


FIGURE 4-26. ATLAS/CENTAUR ORBITER GIMBALLED ANTENNA DESIGN

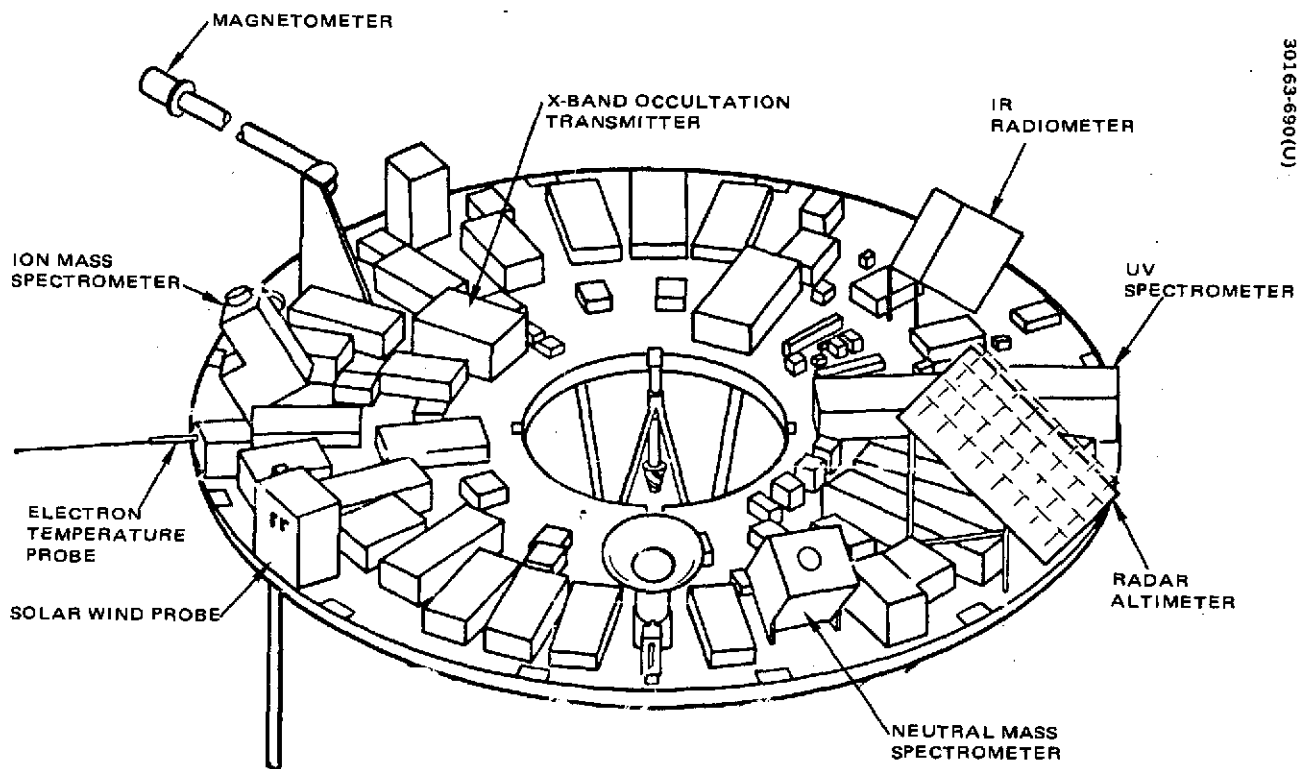


FIGURE 4-27. ATLAS/CENTAUR ORBITER SHELF ARRANGEMENT

TABLE 4-19. MECHANICAL INTEGRATION DETAILS  
FOR ORBITER INSTRUMENTS

Instrument	Pointing Direction	Aperture Size, cm (in.)	Field of View	Size, cm (in.)	
				Electronics	Sensor
Magnetometer	90 deg to spin	—	—	20.3 x 12.7 x 12.7 ( 8.0 x 5.0 x 5.0)	10.2 x 7.6 dia ( 4.0 x 3.0 dia)
Solar wind analyzer	90 deg to spin	2.54 x 0.64 (1.0 x 0.25) 1.27 x 0.64 (0.5 x 0.25)	~140 deg x 20 deg	20.3 x 20.3 x 13.9 ( 8.0 x 8.0 x 5.5)	
Electron temperature probe	90 deg to spin	—	Clear of spacecraft	15.2 x 12.7 x 10.2 ( 6.0 x 5.0 x 4.0)	
Neutral mass spectrometer	Along forward velocity at periapsis	5.08 (2.0)	±30 deg	20.3 x 20.3 x 20.3 ( 8.0 x 8.0 x 8.0)	
Ion mass spectrometer	(56 deg to spin)*	7.62 (3.0)	±30 deg	22.8 x 12.7 x 11.4 ( 9.0 x 5.0 x 4.5)	
UV spectrometer	90 deg to spin	10.16 (4.0)	2 deg	30.5 x 12.7 x 16.5 (12.0 x 5.0 x 6.5)	
IR radiometer	Planet viewing at periapsis (34 deg spin)*	7.62 (3.0)	1 to 2 deg	25.4 x 20.3 x 12.7 (10.0 x 8.0 x 5.0)	
X-band occultation	±20 deg azimuth ±20 deg elevation**	—	3 deg X-band 11 deg S-band	20.3 x 15.2 x 12.7 ( 8.0 x 6.0 x 5.0)	
Radar altimeter	Planet viewing at periapsis ±45 deg elevation (34 deg to spin)*	55.9 x 40.6 (22.0 x 16.0)	30 deg azimuth 14 deg elevation	9832 cm <sup>3</sup> (600 in. <sup>3</sup> )	

\*For type II, 56 deg S lat. orbit

\*\* For gimballed antenna design

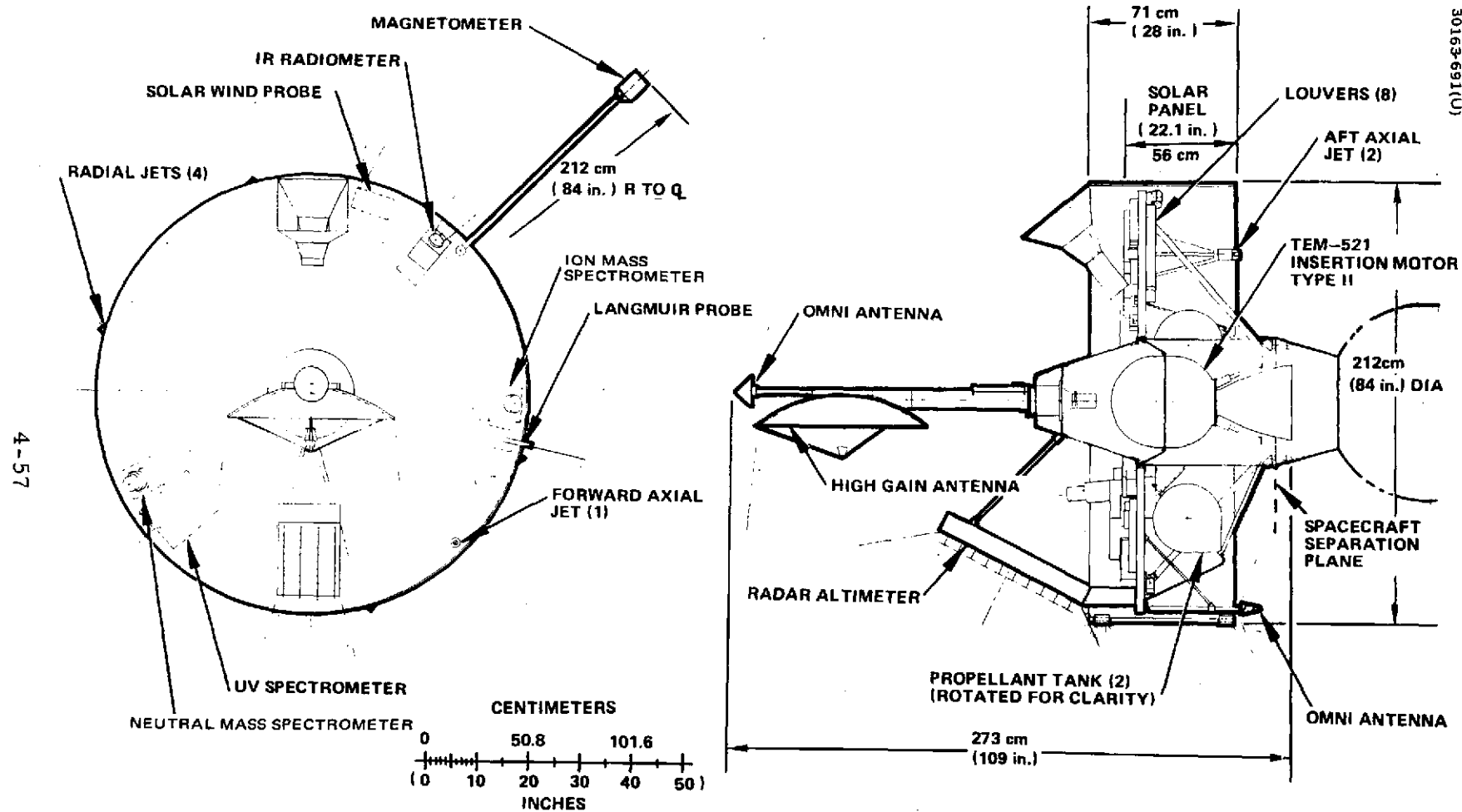
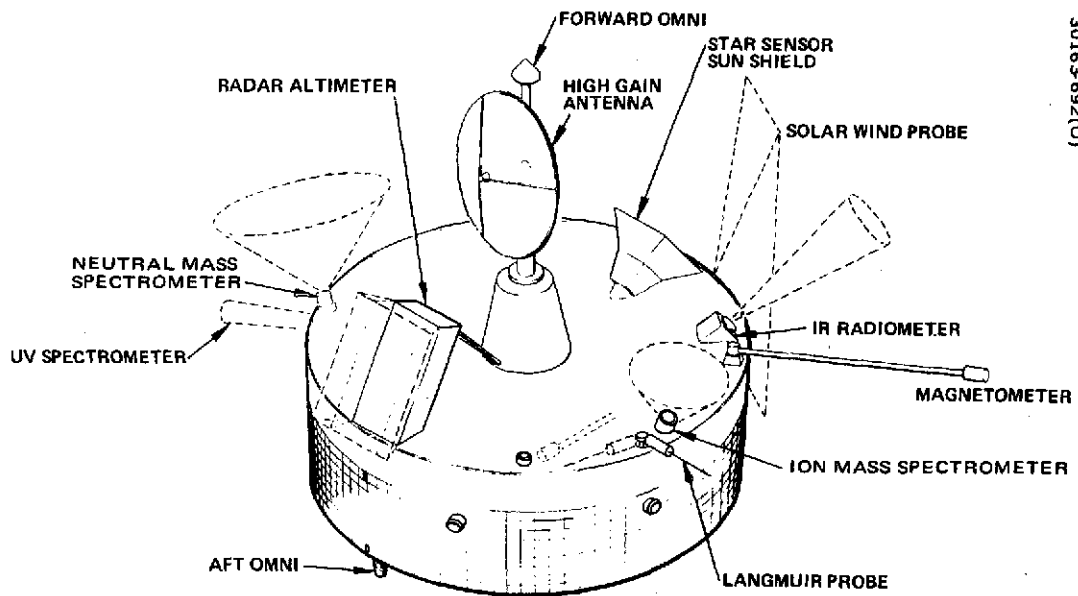


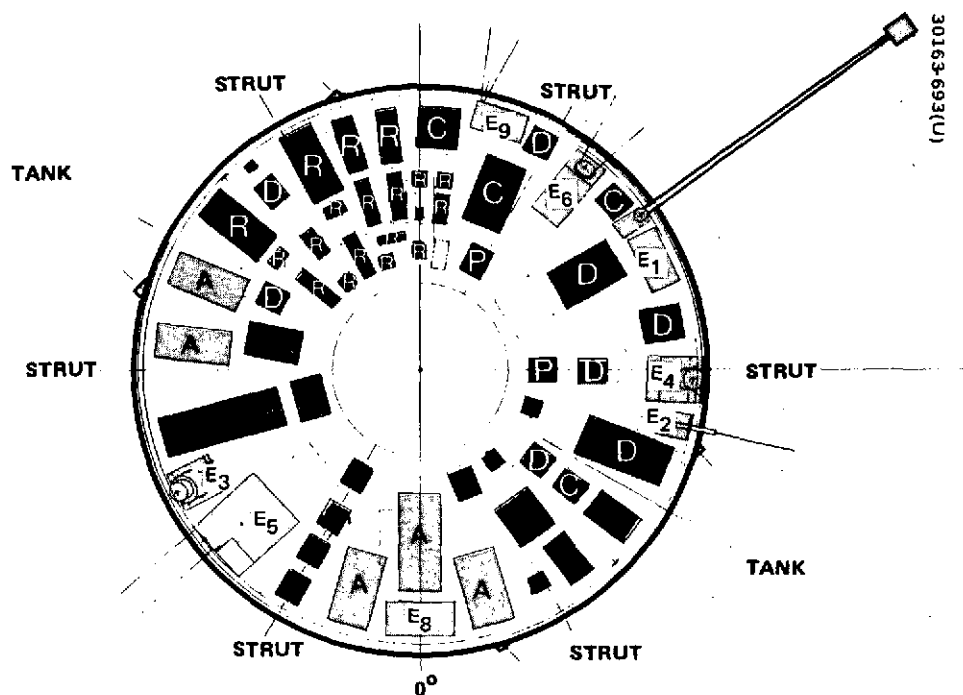
FIGURE 4-28. THOR/DELTA ORBITER SPACECRAFT BASELINE



30163-692(U)

FIGURE 4-29. THOR/DELTA ORBITER EXPERIMENT ACCOMMODATION





#### CODE

E	EXPERIMENTS
E1	MAGNETOMETER
E2	LANGMUIR PROBE
E3	NEUTRAL MASS SPECTROMETER
E4	ION MASS SPECTROMETER
E5	UV SPECTROMETER
E6	IR RADIOMETER
E7	S BAND RADIO OCCULTATION
E8	S BAND RADAR ALTIMETER
E9	SOLAR WIND PROBE
A	ATTITUDE CONTROL SUBSYSTEM
R	RF SUBSYSTEM
D	DATA HANDLING SUBSYSTEM
C	COMMAND SUBSYSTEM
P	POWER SUBSYSTEM

FIGURE 4-30. THOR/DELTA ORBITER SPACECRAFT  
SHELF ARRANGEMENT

### Solar Wind Analyzer

The solar wind instrument is required to scan through the direction of the sun, 360 deg, in the plane of the ecliptic. For this reason, it is mounted on the outer edge of the equipment shelf and views through the substrate above the solar cells at 90 deg to the spin axis. The aperture in the substrate accommodates the large field of view requirements of approximately 140 by 20 deg. The larger angle is parallel to the spacecraft spin axis. Scanning in the ecliptic plane is provided by spacecraft spin of 5 rpm. The sensor and electronics are combined in one unit.

### Electron Temperature Probe

The electron temperature probe is required to be positioned at 90 deg to the spin axis, with a wide field of view. Because it measures charged particles down to very low energies, the instrument is very sensitive to spacecraft charge buildup during passage through the ionosphere. To minimize this charge, exposed surfaces of the solar panels will be coated with a suitable insulating material. (The solar array and all subsystems operate with a conventional negative ground.) The probe utilizes a whip type antenna, located on the upper end of the solar array substrate, which is self-deployed at 90 deg to the spin axis when the aerodynamic fairing is removed after boost. A conducting plane is required around the base of the antenna to serve as a unipotential ground plane, and an area of the substrate is finished to provide this function. Due to extremely low sensor signals ( $\sim 10^{-10}$  A), the electronics unit of the instrument is mounted on the equipment shelf close to the sensor.

### Neutral Mass Spectrometer

The neutral mass spectrometer is required to point within  $\pm 30$  deg of the velocity vector (preferably within  $\pm 15$  deg) over the periapsis measurement region. It is mounted on the equipment shelf to view at an angle of 56 deg to the spacecraft spin axis (predicated on Type II 56 deg south latitude periapsis). At periapsis the forward velocity vector is directly along the instrument aperture. Over the primary measurement region of interest the instrument is within acceptable measurement angles. The pointing direction of the instrument can be changed easily to accommodate different desired sampling regions and periapsis locations, however a more costly pointing capability in orbit would be required to complete mission adaptability.

The neutral mass spectrometer has been positioned away from the magnetometer boom and the charged particle instruments to minimize interference resulting from the focusing magnets which this instrument employs. Also taken into consideration in the positioning is adequate space for the squib-actuated removal of the protective aperture cover after orbit insertion motor firing. Materials and processes used throughout the spacecraft will be screened to ensure that outgassing products do not cause contamination of the instrument. The hydrazine propellant system must also be positioned to direct gas products away from the inlets.

### Ion Mass Spectrometer

The ion mass spectrometer is also required to point along the velocity vector and like the neutral mass spectrometer is offset 56 deg from the spin axis, where it points directly along the velocity vector at periapsis and is within acceptable limits over its primary operating range.

Like the electron temperature probe, the ion mass spectrometer is also concerned with the measurement of low energy charged particles, and the discussion on insulating the surfaces of the solar array applies here as well.

The instrument is positioned on the equipment shelf away from the neutral mass spectrometer to prevent magnetic field interactions. Its position also allows for a squib removed cover.

### UV Spectrometer

This instrument is required to make measurements throughout most of the orbit. Near periapsis, it scans the planet disk and limb. At greater distances, it provides information on the solar wind interaction with the ionosphere. To achieve these results, the instrument has been positioned on the outer edge of the equipment shelf, looking through the substrate above the solar cells at 90 deg to the spin axis. A large aperture has been provided, 10.2 cm (4 in.). The field of view is narrow ( 2 deg) and is unobstructed by any appendage. In this position the instrument will also view the sun, when the spacecraft is not in an eclipse, during a portion of the spin period. This may provide instrument designers with a problem, and necessitate pointing at a smaller angle to the spin axis.

### IR Radiometer

The IR radiometer is required to scan the planet disk at altitudes below 3000 km. It is positioned on the equipment shelf at an angle of 34 deg\* to the spin axis. In this position, the planet surface is mapped through periapsis, and depending on the number of channels and wavelengths, cloud tops and altitude regions could be mapped as well. Provisions have been made in the shelf layout for a large aperture and an unobstructed field of view. The aperture is 7.6 cm (3 in.) and the field of view approximately 2 deg.

### X band Occultation

The X band occultation experiment adds a second frequency to the existing S band communications frequency, providing a dual frequency occultation experiment, and permitting increased information to be obtained on the Venus atmosphere as earth is occulted by Venus. Azimuth and elevation rotation of the antenna is required if the beams are to be kept on earth during  $\pm 20^\circ$  of deflection caused by the Venusian atmosphere.

\* This angle is based on a Type II 56° S latitude orbit. Other angles can be accommodated with no design impacts.

Part of the experiment, the S band, comprises the orbiter RF subsystem downlink, which consists of the experiment shelf mounted transmitter and high gain despun antenna unit. The addition of X band modifies this system by adding the X band transmitter, additional feeds, and rotary joints to the high gain antenna and an X band antenna feed.

The high gain antenna is positioned on the spin axis, pointing at 90 deg, and despun from the remainder of the spacecraft, as shown in Figure 4-26.

Recently the requirement to maintain the antenna beams on earth during atmospheric deflection has been reviewed by NASA/ARC and reduced to  $\pm 10$  deg. As a result of this updated requirement the S and X band experiment was reevaluated. Several different techniques were considered as shown in Table 4-20. As a result of this tradeoff study it now appears that the most cost effective technique is that shown in configuration A. It employs a separate X band horn mounted on top of the high gain antenna. Both antennas are despun, but have no elevation rotation as in the previous baseline. Analysis has shown that sufficient margin exists to provide a look angle up to the  $\pm 10$  deg. However, should it be desired to increase this capability, this particular design would not be satisfactory. The technical proposal will provide further details on this experiment. It remains to be seen whether the science requirements permit operation on the steep edge of the beam.

#### Radar Altimeter

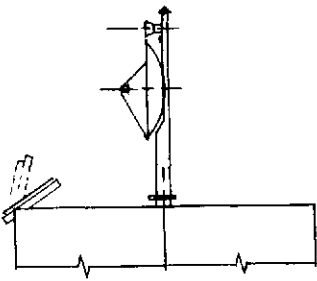
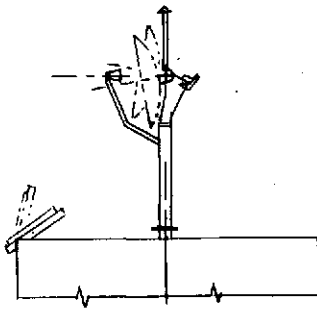
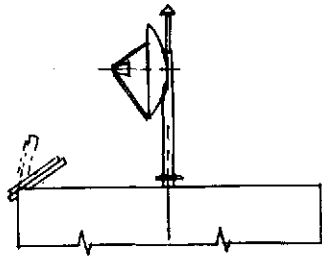
The radar altimeter is required to carry out planetary mapping at altitudes below 1000 km. It consists of an electronics unit and a large planar array antenna. The antenna is positioned above the equipment shelf and its beam is angled at 34 deg to the spacecraft spin axis to coincide with the south periapsis latitude location. An electronic beam steering capability of  $\pm 45$  deg in elevation (parallel to spin axis) permits the radar to point down along the local vertical during each planet scan, providing the 1000 km altitude capability over the measurement region. The electronics unit is mounted on the equipment shelf in close proximity to the antenna. The antenna array may be positioned for other periapsis rotations, up to perpendicular to the spin axis if required, with no spacecraft modification required. The 56 deg periapsis latitude was chosen to provide maximum mid latitude coverage of the planet. The VOSSG recommended a periapsis latitude of 45 deg and an inclination of greater than 60 deg.

Because of the size of the antenna and the need to avoid interference with the communication antenna, this instrument initially sizes the antenna mast height.

#### Thermal Control Considerations

The science instruments are mounted to the spacecraft equipment shelf which is thermally controlled through the use of variable emittance thermal louvers and multilayer thermal insulation. The insulation system isolates the equipment shelf from the large changes in environmental conditions (increasing

TABLE 4-20. DUAL FREQUENCY OCCULTATION TRADES

Configuration (All antenna assemblies are despun in azimuth)				
Design approach		Fixed S band HGA, Separate X band horn 33 W X band transmitter	Moving HGA reflector Fixed S/X feed 0.2 W X band transmitter	Moving spacecraft Fixed antenna with S/X feed 3 W X band transmitter
Increases to add occultation experiment	Cost K\$	750	1020	770
	Mass, kg (lb)	5.26 (11.6)	8.40 (18.5)	7.67 (16.9) for 40 days.
Reliability		Best	Must accommodate elevation drive failure	Additional thruster pulses required
Science		Adequate (to $\pm 10$ deg), pointing accuracy $< 1$ deg. Best interface (separate X band)	Best boresight to earth, $\pm 20$ deg, pointing accuracy $< 1$ deg	Worst attitude uncertainty, pointing accuracy $< 2.5$ deg. Impacts radar altimeter usage
Mission operations		Best	Some additional operations	Worst — requires daily attitude control. Uses 1.9 kg (4.2 lb) propellant in 40 days at $\pm 10$ deg

solar intensity, varying sun angles, eclipsing) and the louvers, which are activated by shelf temperature changes, compensate for changes in the electrical dissipations on the shelf.

In the shelf thermal design, consideration was given to instrument power dissipation, mounting surfaces, instrument duty cycles, and aperture characteristics.

The instrument mounting surfaces will be maintained within the range of 4° to 38° C (40 to 100° F) during operation. Detailed discussion of the spacecraft thermal design is given in Section 5 of Volume 4 (Probe Bus and Orbiter Spacecraft Trade Studies).

### Electrical Power

The electrical power to the instruments is provided by the solar array and a Ni-Cad battery. The battery is used during those periods when the orbiter is occulted from the sun by the planet and when load transients exceed the capability of the array.

The electrical power to the instruments of the orbiter is +23 to +33 Vdc. Any additional regulation will be accommodated within the individual instruments. Separate and commandable power switching is provided to each instrument and bus protection is provided in the form of overload trips which protect against inadvertent failure of any one instrument. Two overload circuits handle all nine instruments.

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APPENDIX TO VOLUME 2

SCIENCE TRIP REPORTS

## PREFACE

This appendix is a collection of the science trip reports written to document visits to scientists made during the Pioneer Venus study to obtain a better understanding of experiment requirements and characteristics.

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# CONTENTS

		<u>Page</u>
1.	PIONEER VENUS SCIENCE BRIEFING MINUTES	HS 507/0225 A-9
2.	SCIENCE TRIP REPORT: 25 to 30 September 1972	A-25
2.1	A.I. Stewart, U. of Colorado - UV Spectrometers	HS 507/0224 A-27
2.2	R. Young, York University - UV Fluorescence	HS 507/0226 A-39
2.3	N.W. Spencer, NASA GSFC - Mass Spectrometer	HS 507/0230 A-57
2.4	J.S. Lewis, MIT - Venus Atmosphere and Clouds	HS 507/0220 A-89
2.5	I.I. Shapiro, MIT - DLBI	HS 507/0220 A-103
3.	SPACE OPTICS MEETING - 13 October 1972 - A. G. Monfils, U. of Liege - ESRO UV Spectrometer	HS 507/0237 A-105
4.	McELROY SCIENCE BRIEFING - 20 October 1972	HS 507/0253 A-117
5.	SCIENCE TRIP REPORT: 1 to 3 November 1972	A-123
5.1	W.B. Hanson, U. of Texas - Upper Atmosphere Experiments	HS 507/0260 A-125
5.2	J.W. Bryan, NASA/GSFC - RF Altimeters	HS 507/0260 A-129
5.3	Singer Kearfott - Wind-Drift/Altimeter Radar	HS 507/0273 A-159
6.	AMES VISITS - 9 November 1972	
6.1	T. Grant - Orbiter Radio Science Redefinition Meeting	HS 507/0267 A-173
6.2	L. Polaski - Cloud Particle Analyzer, Shock Layer Radiometer	HS 507/0269 A-205
7.	INFORMAL DESIGN REVIEW - 1 December 1972 J. Sperans - Splinter Meeting on Experiment Integration	HS 507/0324 A-209
8.	VISIT TO HUGHES OF J. SPERANS AND L. POLASKI - 8 December 1972	HS 507/0338 A-215
9.	AAAS MEETING ON NASA PLANETARY RESEARCH - 29 December 1972	A-221
9.1	J. Naugle - NASA's Planetary Program, Past- Present-Future	HS 507/0377 A-225
9.2	T. Donahue - The Mysteries of Venus	HS 507/0370 A-231
9.3	S.I. Rasool - Atmospheres of Mars, Venus, Earth	HS 507/0478 A-235
9.4	H. Masursky, C. Leovy - Mars, After Mariner 9	HS 507/0531 A-239
9.5	W.I. Axford - Survey of Fields and Particles Measurements	HS 507/0531 A-243
9.6	R. Jastrow - Planetary Exploration and the Future of Man	HS 507/0478 A-249

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# Contents (Continued)

		<u>Page</u>
10.	SBRC VISIT - 3 January 1973 S. Chase - Orbiter Infrared Radiometer	HS 507/0368 A-253
11.	JPL VISIT - 11 January 1973	
	11.1 W. E. Brown - Radar Altimeter	HS 507/0383 A-255
	11.2 A. J. Kliore - Radio Occultation	HS 507/0383 A-257
12.	AMES VISIT - 11 January 1973 J. Sperans - Magnetometer Study Results	HS 507/0382 A-259
13.	SIGMA XI LECTURE - 18 January 1973 H. Alfven - Evolution of the Solar System	HS 507/0404 A-263
14.	McELROY SCIENCE BRIEFING - 31 January 1973	HS 507/0413 A-273
15.	STANFORD VISIT - 9 February 1973 Von R. Eshleman - Radio Occultation	HS 507/0433 A-285
16.	NASA/ARC SCIENCE BRIEFING - 13 February 1973	HS 507/0434 A-289
17.	AMES VISIT - 9 March 1973 - S.C. Sommer - Accelerometer, Pressure and Temperature Sensors	HS 507/0455 A-299
18.	TRW VISIT - 12 March 1973	A-301
	18.1 M. Kolpin - Mass Spectrometer Inlet System	HS 507/0461
	18.2 L. Harnett - Hygrometer	HS 507/0461
19.	RECENT SOVIET PAPERS DEALING WITH VENUS MISSIONS	HS 507/0467 A-303
20.	EXPECTED BEAM TRACK DURING OCCULTATION	JPL Letter A-310
21.	SCIENCE TRIP REPORT - 19 March 1973 R. Knollenberg - Cloud Particle Analyzer - A.I. Stewart - UV Spectrometers	HS 507/0480 A-315 HS 507/0480 A-316
22.	PLANETARY SCIENCES MEETING IN TUCSON - 20 to 23 March 1973	HS 507/0532 A-321
23.	SCIENCE TRIP REPORT - 5, 6 April 1973	
	23.1 V. Suomi, U. of Wisconsin - Small Probe Experiments	HS 507/0489 A-343
	23.2 W. Fastie, John Hopkins U - UV Spectrometer	HS 507/0489 A-344

Contents (Continued)

	<u>Page</u>
23.3 R. Hanel, NASA GSFC - Nephelometer	HS 507/0489 A-345
24. JPL VISIT - 9 April 1973	
A. Young - Sulfuric Acid Clouds on Venus	HS 507/0497 A-347
25. JPL VISIT - 13 April 1973	
A. L. Fymat - Solar Flux Radiometer	HS 507/0534 A-349



HUGHES AIRCRAFT COMPANY



1.0 INTERDEPARTMENTAL CORRESPONDENCE

TO: Distribution "D"      cc:  
ORG:  
  
SUBJECT: Pioneer Venus Science  
Briefing Minutes

DATE: 12 October 1972  
REF. HS507/0225

FROM: A. M. Lauletta  
ORG. 44-24

BLDG. 376      MAIL STA. 11115  
EXT. 84509

On 4 October 1972, the first Pioneer Venus Science Briefing was held at NASA/ARC Mountainview, California.

The first session of this meeting was presented by NASA to kick-off the system definition study which will be reported on elsewhere.

The second session of this meeting was to provide a science briefing by NASA and key scientists involved with the Pioneer Venus exploration program.

The science briefing was held in two parts. The first part was a joint session, including both study contractors, Hughes, TRW and their sub-contractors; the second part was an individual science briefing with only one contractor in attendance, thus allowing questions which would maintain the competitiveness of the dual study approach.

The notes and minutes attached hereto, prepared in excellent fashion by Dr. L. K. Acheson, deals with both parts of the science briefing.

There were twelve (12) key questions asked by Hughes in hopes of opening the door to further questions and answers to aid our system design study.

It appeared to be a successful meeting, providing Hughes with a better understanding of some of the critical science objectives. I believe we also left NASA/ARC and the science community with a deeper understanding of some of the system problems. This type of interchange is quite useful for all parties.

The participants in the science briefing included all of Hughes and NASA personnel who were in the morning session. A panel of scientists which included:

Dr. L. Colin  
Dr. R. M. Goody  
Dr. D. M. Hunten  
Dr. A. F. Nagy

NASA/ARC Project Scientist  
Harvard University  
Kitt Peak Observatory  
University of Michigan

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A-9

Attachments

A. M. Lauletta, Jr.

## PIONEER VENUS PHASE B CONTRACT KICK-OFF MEETING

### INTRODUCTION

Dr. Hans Mark, Ames Research Center

Why are we in this business? There is a simple reason. Ames is a leading NASA institute for re-entry into the earth's atmosphere, and for study of other planets, and is very anxious to be in on the first U.S. entry of a little-known planet. We are very committed to seeing this program through. I won't talk about money, but we must try to do things as cleverly as possible to reduce cost.

Dr. John Foster, Ames Research Center, Director for Development

It is important to get off on the right foot with regard to objectives. There are two tasks to be considered: First, the existing contract signed a few weeks ago, and second, to look at the Atlas-Centaur booster.

With regard to the existing contract, I want to emphasize that the program has been sold from the start as a low-cost mission. Both the science community and NASA have said this. The people who must implement this low cost are the people in this room. (By low cost, we mean credible low cost.) In discussions with George Low, if there is one point he has made, it is this, that he wants to make this a showcase project with regard to low cost. One must use both the best innovative methods and proven designs.

When one looks at the total cost to the taxpayers -- booster cost plus payload cost plus operating cost -- Dr. Low wants to make a tradeoff with regard to using a larger boost capability if it can reduce the payload cost.

What is the baseline experiment payload on which we should conduct these studies? If we pick the baseline to have minimum science, then we have constrained ourselves unduly regarding further growth. On the other hand, if we allow too much payload growth, the payload cost will rise.

If one is truly to make a comparison between the Atlas and the Delta, however, it is our experience that experiments have a greater growth potential in cost than any other element of the system, and we have to consider allowing more space, weight and volume, for the experiments. Our dilemma is that we went out for equal payload weight and volume in the booster studies, and this will require modification. In making a cost comparison, we have the further dilemma that your comparisons will be made in terms of Phase C and D cost estimates, whereas the cost of the boosters will have to be brought in as ultimate costs.

The final thought is to constantly bear in mind the low-cost aspect of this program.

Daniel Herman, NASA Headquarters, Program Manager

I will be talking about money because we are in the throes of formulating the FY '73 budget. Cost growth won't be tolerated. The program will be cancelled if there is cost growth. We believe that one can get more science/dollar by



cancelling cost growth programs than by not making new starts. The selling points for Pioneer Venus are its potential science/dollar value and that elements of the program have prospects for growth beyond Venus itself.

Philosophically, George Low is correct -- if we can see how to constrain performance and see how a larger launch vehicle can result in a lower cost spacecraft. The biggest cost driver is peoples salaries. Anything that can be done to minimize analysis, testing, and the utilization of people is desirable.

Due to the fact that the basic design of Mariner is based on the severely weight limited Mariner 4, the structure is extremely costly to build. If we didn't have the weight constraint, we could have saved one million dollars.

One consideration in comparing Atlas with Delta might be in relation to the number of launches.

We want an honest technical assessment, not a political assessment.

## SCIENCE BRIEFING

## INTRODUCTION AND SCIENCE PAYLOAD

Dr. Colin - Project Scientist, NASA/ARC

This is not intended to be a briefing, but a question and answer period. The purple book has been the bible for many years. The new bible is the orange book. The major authors will be sitting around the table here.

Joel Sperans will comment on the differences between the orange book payload and the NASA payload. The SSG, which disbanded in July, produced an orbiter payload. Immediately afterward, a joint NASA/ESRO orbiter SSG was formed, and has been working the payload for several months. The Joel payload reflects quite closely what the NASA/ESRO payload looks like today.

Joel Sperans - Experiments Manager, NASA/ARC

The last three items on the large probe nominal payload (nephelometer, shock layer radiometer, and hygrometer) are not category A instruments in the SSG listing, but have been included in the nominal payload because we feel they have a good chance of being on the final payload. This is somewhat arbitrary.

The "other candidate instruments" on the large probe we don't want included. They have been listed here because they pose interesting and challenging problems and we feel they have a finite chance of being included.

Wind Drift Radar - A first look tells us this is an extremely feasible device. An off-the-shelf low-cost instrument can be used; however, it has an enormous impact on the probe. It requires a large antenna or several small antennas and causes thermal problems.

Fluorescence Spectrometer - Hasn't been precisely defined yet. There are three or four candidates. We think the weight and size is representative of all types. These instruments require a thin window.

Noise Detector and Spherics Detector - These two items were included as an afterthought. They are not in the SSG report, but several persons have proposed them and they present some different engineering problems with regard to antennas.

For the small probes, only a nominal payload is presented. A footnote to the SSG says that only the first three are essential for a minimum payload (i. e., the least payload to justify use of small probes), but all are desirable. We want the system design to include all of these instruments.

The weights shown are conservative weights; we are very confident we can meet them. In order to minimize the weight, we may build the entire payload, rather than having each experimenter build his own. The temperature and pressure gauges we feel can be decreased in weight.

For the probe bus, the nominal payload corresponds exactly to the SSG report category A payload. Other candidate instruments have been given (the lower priority SSG instruments), but we feel there is a severe weight limit for the probe bus, and that these shouldn't be put in the nominal design.

For the orbiter, this is a hybrid payload. We tried to preserve the spirit of the SSG payload and yet incorporate some of the thinking of ESRO. We don't know to what extent this will differ from the final NASA/ESRO payload. We have also included some "other candidate instruments" for the orbiter.

Dr. A. F. Nagy - University of Michigan

Having participated in the NASA/ESRO discussions, I can comment that this payload differs from the orange book in that it is smaller -- a couple of category A experiments have been downgraded to category B. It has not yet been firmed up. The solar wind experiment, however, even in the ESRO payload was category A, whereas it appears here in the NASA payload in the "other candidate instrument" category.

#### CONTRACTOR A SCIENCE BRIEFING (TRW/Martin excluded)

Tony Lauletta - Hughes Aircraft Company

To what extent is parachute blockage a problem for upward viewing instruments, i. e., the solar flux sensor?

Joel Sperans

There are several designs for solar flux instruments and these vary considerably with respect to this problem. Some instruments have single windows, and some have dual windows.

Some studies done at Ames indicate that since the sun is near the horizon, we feel you don't need to look up.

Dr. D. M. Hunten - Kitt Peak Observatory

It makes a difference whether you are talking about measuring the direct radiation from the sun or measuring the diffuse flux.

Dr. R. Goody - Harvard University

This instrument hasn't been thoroughly thought out. One could look at a narrow portion of the sky and deduce the total flux, but the simplest mode would try to take in the entire hemisphere. This is the ideal. For this case, however, one can compute the degree of blockage. (One must assume that the sun is not being blocked.) A 10% blockage could be easily handled, assuming one knows the geometric blocking.

Tony Lauletta

Can you describe the intended application of the RF science experiments in the orbiter?

Dr. Nagy

Unfortunately, there is no straight answer. A large number of possibilities are being discussed. These include:

- o a large tiltable antenna serving both the communications and the RF science
- o The spacecraft pointed in the ecliptic with a fixed communications antenna at the end and a separate radar antenna.

If there is an electronically despun antenna, one also requires a separate radar antenna.

With regard to the 20 pounds assigned to the RF payload, this is the extra weight for these experiments in addition to what weight antenna would be present for telecommunications. I.e., assume we have a spacecraft with no radar experiment, then take the spacecraft with the radar experiment -- what extra weight must be added? The number cooked up was about 20 pounds, without freezing the design. Of course, this may be way off.

Terry Grant - Communications and Data Systems, NASA/ARC

The SSG weight estimate was based on assuming a despun communications antenna. One would have to take the difference between this and a tiltable TM/radar antenna.

Dr. Nagy

With regard to the use of S- and X-band, this started out from the two frequency occultation experiment. Then a radar expert looked at the radar altimeter question, and I am under the impression that the same RF package would be used, alternatively, for both.

Terry Grant

I am not clear about this. The concept for use of X-band has been left to Dr. Pettingill. There are letters of intent from scientists who propose using other than S-band.

Dr. Nagy

At the 23 October ESRO/NASA meeting, we must get a better feeling for how good this 20-pound estimate is.

Tony Lauletta

Can you comment on the necessity for the large and small probes to reach the surface?

Dr. Goody

I thought this was clearly stated in the SSG report. There is little need for the probes to determine exactly where the surface is. If we got measurements down to 1 or 2 km of the surface, or even half a scale height (5 km), the atmospheric mission would be successful.

We feel strongly that no cost should be expended to reach the surface. (There should be no risk factor to ensure reaching the surface.) There is no difference between the large and small probes in this respect, although we would like (hope) to get a seismometer reading from the large probe.

Dr. Hunten

We would also like to get a reading on the stable oscillator from a small probe on the surface.

Tony Lauletta

What would you say are the most critical science factors affecting probe descent rate?

Lou Polaski - Experiments, NASA/ARC

Looking at the SSG report, and with regard to the mass spectrometer, if we can make measurements within the cloud layer, then we can infer what the clouds are made of. We looked to see if at least one full measurement was made within the cloud layer, and it turned out the limiting factor was the data transmission. With the mass spectrometer, you could make a scan in 10 to 20 seconds, but it took 3 minutes to transmit the data at 40 bits/sec.

Dr. Hunten

A couple of seconds should be sufficient for the mass spectrometer measurements. Goody and I think that the only instrument which might have problems is the cloud particle analyzer. We have some qualms about going several hundred m/sec and still observing small particles.

Dr. Goody

This is a problem we have been around and around several times. The proposed descent rate doesn't appear to present any fundamental restrictions on the science. For example, it is sufficient if the mass spectrometer can do a measurement once every scale height. Perhaps we don't even need the parachute. One of the things you people should be trying to find out is if this descent rate costs you much.

Tony Lauletta

There does appear to be a considerable weight savings on the probe to get out on the parachute at 65 km say rather than at 70 km.

Dr. Goody

You can get much argument about this in groups of scientists. But the SSG report makes clear that these probes are lower atmosphere probes, so it makes no sense to pay weight in going from 65 km to 70 km. And since the orbiter will have IR to probe the regions above the clouds, we particularly don't need this.

Tony Lauletta

What is the priority of mass spectrometer measurements with regard to altitude?

Dr. Hunten

The most important measurement of the mass spectrometer is the lowest one. The origin of the material that makes up the clouds will be in the lower atmosphere. So there is great emphasis on the lower layers.

Jack Fisher - Hughes Aircraft Company

The lower parachute release level of 45 km appears to coincide with the bottom of the lower cloud level. Was this intentional?

Dr. Goody

It is pure chance if this coincided with the lower cloud layer. The release altitude was determined by the fact that we wanted to try to keep about the same average velocity.

Si Sommer - Probes, NASA/ARC

From the point of aerodynamic stability, we might still want parachutes. The Russians used parachutes all the way to the surface.

Dr. Goody

In Venera 5, they used parachutes at low altitude, but none of the Russians to whom I talked seemed to know why.

Tony Lauletta

What are the most critical science factors affecting the probe spin rates, and probe bus spin rates?

Dr. Goody

We want a slow steady spin on the small probes for the magnetometer. But there is a wide range of latitude on spin rates. It is not critical. Also on the large probe, nothing is critical with regard to spin rate.

Si Sommer

We would require less samples of accelerometer data if the probe is spinning to obtain aerodynamic information.

Dr. Nagy

For the probe bus spin is needed for the mass spectrometer.

Dr. Hunten

The neutral mass spectrometer outlets must be pointed straight forward or sideways. There are some proposals to sample the inlet ram.

Dr. Nagy

It depends on who proposes the mass spectrometer experiment. Some want to see ram and some want spinning. Those who want to see it spinning want a small rate, 5 to 10 rpm perhaps, with 3 or 4 sec/scan.

Dr. Hunten

I can't let that pass too quickly. Most experiments want a small spin because of data rate considerations. With a few hundred bits/sec, one may not afford 5 to 8 rpm.

Dr. Nagy

For the orbiter, 3 to 6 rpm appears to be a reasonable, achievable rate.

Tony Lauletta

Should data handling format capabilities be adaptable to measurement changes?

Lou Polaski

We looked at the question of an adaptive mass spectrometer but discarded the idea because it required a higher S/N.

Dr. Hunten

There is the additional problem of decoding on the ground. If a glitch occurs, the data may be lost.

John Dyer - Mission Analysis and Operations, NASA/ARC

One must also evaluate the cost impact at the ground.

Dr. Goody

I am trying hard to think of any value for adaptive processing. There will be some dedicated cloud instruments, and if no clouds are there, then perhaps it would be of some use, but I don't think the experimenters want their instruments turned off and on; they would be afraid of missing some important data. I believe it would be of very little value. Later downstream, it might be considered perhaps.

Tony Lauletta

Would you quantify the requirement which states that the magnetic properties of the spacecraft and probes shall be consistent with the scientific objectives?

Dr. Goody

We were assured that the plan to put the magnetometer on the miniprobes (rather than the large probe) was because they were easier to keep clean, and an estimate of \$200,000 was given of the cost to keep them clean. Figures are given in the SSG report on the level of cleanliness.

On the probe bus, it was assumed that the boom could be made long enough to meet cleanliness requirements without a cost impact.

Tony Lauletta

Is there any requirement to turn on the miniprobe magnetometers early (prior to re-entry) to make measurements of the ionospheric fields or to calibrate with the probe bus magnetometer?

Dr. Hunten

I feel that turning on the small probe for a short period early would be of value.

Tony Lauletta

What are the most critical science factors affecting the choice of an orbit?

Dr. Nagy

There is no direct answer to that question. All 12 experimenters have different ideas, but there was a fairly close consensus that a high inclination orbit (60-deg. or over) was desirable, with a periapsis latitude of about 30 degrees. (some sensors wanted 30 to 50 degrees, and some wanted less than 30 degrees, so 30 degrees was the compromise), and a periapsis altitude of 200 km.

With regard to the question of whether there is any advantage to starting at 400 km and dropping to 200 km, most in situ experiments want as low an altitude as possible. One could start at 400 km and drop to 200 km a few days later, but there would be a lot of unhappiness if one stayed at 400 km for any length of time greater than a few days.

Dr. Hunten

Unless one is doing celestial mechanics experiments.

Dr. Nagy

But an overwhelming majority want low altitude.

Dr. Hunten

If one went by majority vote, there wouldn't be any magnetometers on board.

R. Jackson - NASA/ARC

There will be a variation of periapsis and it will cost fuel to maintain.

Dr. Nagy

Somebody dropped a bomb at the last orbiter SSG meeting that periapsis would be increasing at 10 to 20 km/day.

Robert Nunamaker - Study Manager, NASA/ARC

ESRO has done quite a bit of work on the orbiter mission. We must determine whether we want to hold a given altitude for a length of time. One 400 km orbit raised to 500 km and lowered to 250 km with a period of about 20 days. For certain orbital parameters, the altitude will increase, for others, it will decrease, and there is a possibility that some will stay still.



Daniel Herman - Program Manager, NASA Headquarters

Because of this phenomena, the idea of circularizing the orbit by atmospheric drag is completely infeasible.

Dr. Hunten

But when you are at low altitudes, this would not be as big a factor.

Robert Nunamaker

ESRO has the idea that a 24-hour orbit is sacred, but this should be traded off.

John Dyer

But the 24-hour orbit was picked also for DSN scheduling.

Tony Lauletta

Can you give us some idea of how sensitive this 200 km figure is?

Dr. Nagy

It is hard to quantify. The lower the altitude, the better you are. The project said that 200 km could be lived with.

Dr. Hunten

Every scale height you lose is a serious loss of data on the atmosphere.

Robert Nunamaker

We feel that the thermal control problem is a factor to keep away from dipping too low.

Dr. Hunten

But after the first orbit, we will know how serious this is and can adjust the orbit accordingly.

Tony Lauletta

What are the most critical science factors affecting the orientation of the spin axis?

Dr. Hunten

You either spend a day discussing this, or say it is so complicated that it can't be answered.

Dr. Nagy

The only obvious impact is on the solar wind detector, which does not like spinning in the ecliptic plane. During its lifetime, it wants to look at the sun. Beyond that, it is not immediately obvious. The spin axis orientation impacts seriously the radar experiment.

Dr. Hunten

It impacts the UV, IR, and everything!

Dr. Nagy

Offhand, I would say, yes, it strongly impacts them, but it is not clear which is better. Last November at the first orbiter meeting, it was generally felt that one orientation was best. At the second meeting, however, it wasn't so clear.

R. Jackson

We haven't heard any feedback that any one spin axis is better or worse than another.

Dr. Hunten

I feel this is a horrendous problem which we have only begun to touch, and we will hear screams of anguish from the experimenters when they become aware of the situation.

Tony Lauletta

What are the most critical factors affecting the orbiter spin rate?

Dr. Nagy

We were told that 4 to 6 rpm are possible for the orbiter, and decided that the experiments could live with this but not much higher.

Daniel Herman

The question was, from a science standpoint alone, would you like a lower spin rate. Some experiments definitely want a spinning spacecraft. The spin rate should be small, but I would think, for example, that 0.01 rpm would be too low. The Phase B contractor must determine what spin rate(s) he can provide.

Dr. Goody

This is another can of worms. The SSG is not enthusiastic about imaging, but ESRO is strong for imaging and may want a large spin rate.

Dr. Colin - Project Scientist, NASA/ARC

We are not adding a spin scan TV to the payload!

Dr. Nagy

It is clear that on the orbiter, half a million bits of data storage will be needed.

Tony Lauletta

What do you consider the most critical science integration problem for the probes, probe bus, and orbiter?

Dr. Goody

The miniprobes seemed extremely difficult to the SSG from an experiment integration standpoint, but also the large probe presents problems.

Dr. Nagy

The inlet system of the mass spectrometer won't work if the project provides the inlet system and the experimenter the mass spectrometer.

Dr. Goody

This is the engineering challenge.

John Bozajian - Hughes Aircraft Company

The question of spin axis orientation is a critical one for the spacecraft design. Did I get the impression that you feel it doesn't matter to the experimenters what the orientation is?

Dr. Hunten

I hope you didn't get that impression from me. I feel that the spin axis problem is certainly critical and feel that you shouldn't constrain your spin axis to a rigid direction. I believe that you need a universal telemetry antenna so you can use any spin axis. A spin axis fixed in the ecliptic plane would be totally unacceptable.

Dr. Nagy

I may have given a misleading answer. The problem is so complex that the experimenters don't know how to answer, except for the solar wind.

Joel Sperans

Six months from now, this will be much easier to answer when the experiments have been selected.

Dr. Hunten

But this is an orbiter problem.

J. Dyer

I had felt that this was a binary question, with the spin axis either normal to the ecliptic or in the ecliptic, but are there other possibilities?

Dr. Nagy

The only guide we have now is a preference for normal to the ecliptic in the SSG.

R. Jackson

There doesn't appear to be a clear advantage to either.

Jack Fisher

When considering additional instruments to the nominal payloads, how should these be treated?

Joel Sperans

They should be considered as individual additions to the baseline and not as replacements.

(Questions from audience to Nunamaker on the ESRO Radio Astronomy Antenna)

Robert Nunamaker

Effelsberg is a 100 m S-band antenna built by West Germany, but Effelsberg doesn't want to track spacecraft, they feel it was made for radio astronomy. It is not operational yet, but will be used to track Helios. It is a receive only station.

Robert Nunamaker

I would like to ask the contractor about the value of this type of science meeting versus visiting the experimenters.

Tony Lauletta

This type of meeting is very valuable. It gives a chance for my management to hear some of these things directly rather than second hand.

Dr. Goody

I would make one comment. To bring this program off in a successful way, requires a great deal of self-discipline of scientists. It is important to get the community view, rather than everyone's individual views. It is simply not possible to fit everyone's individual views into an integrated whole.

NOTE: Meeting was adjourned. Hughes was taken on a facility tour while contractor B, TRW, held their science briefing.

## 2.0 INTERDEPARTMENTAL CORRESPONDENCE

TO: Distribution CC: DATE: 12 October 1972  
ORG: REF. HS507-0224  
SUBJECT: Science Trip Report FROM: A. Lauletta /L. Acheson  
25 September 1972 to ORG.  
30 September 1972  
BLDG. 376 MAIL STA. 11141  
EXT. 84509

Several scientists associated with the 1972 Pioneer Venus Science Steering Group report were contacted to provide a further understanding of the science requirements as they would effect system and mission requirements. In addition, a better understanding of experiment accommodation was hopefully sought.

An attempt was made to contact those people who were not contacted previously in order to provide a community wide input to understanding the experiment integration requirements.

The information contained herein is to be used cautiously since our direction for payload and system requirements comes from NASA/ARC.

The itinerary was as follows:

September 26	Dr. A. I. Stewart	University of Colorado
September 27	Dr. R. Young	York University
September 28	N. W. Spencer	NASA/GSFC
September 29	Dr. J. S. Lewis	MIT
September 29	Dr. I. I. Shapiro	MIT
September 30	Dr. M. B. McElroy	Harvard University

Attached are the discussions with Dr. A. I. Stewart of the University of Colorado. The remaining portion of the trip report shall be forthcoming.

**Distribution:**

  
A. Lauletta

L. K. Acheson  
J. M. Bozajian  
S. D. Dorfman  
B. P. Dagarin  
J. N. Fisher  
A. M. Lauletta  
R. R. Mullen  
D. M. Newlands  
L. T. Nolte  
H. D. Palmer  
C. Thorpe

R. J. Varga  
Data Bank (2)  
R. R. Nunamaker (2), NASA/ARC

A-25

## PIONEER VENUS SCIENCE TRIP REPORT

### 2.1 UNIVERSITY OF COLORADO, 26 SEPTEMBER 1972

#### Introduction and Summary

A visit was made to the Laboratory for Atmospheric and Space Physics at the University of Colorado to talk to Dr. A. I. Stewart about UV spectrometers.

The latest Ames orbiter payload shows a factor of three increase in the weight allotted to the UV spectrometer so that at 12 lb it is now the largest single orbiter instrument (apart from the 20 lb radio science complex). The SSG report listed papers by Barth and Stewart at the University of Colorado as references for the ultraviolet spectrometer. Their spectrometer has been flown on Mariner 6, 7, and 9.

The key facts learned during this visit are:

- They would prefer to operate the spectrometer in a spinning mode (Pioneer Venus) than in a pointed mode (Mariner).
- A spin rate of 4 or 5 rpm would present no particular problems.\*
- The preferred spin axis orientation is perpendicular to the orbit plane.
- Near periapsis the best airglow data would be obtained; at mid-regions useful data can be obtained from the planet disk; during the rest of the orbit the spectrometer would focus on hydrogen Lyman  $\alpha$  radiation from space.
- The greatest amount of data is desired near periapsis. Data storage would be required.

\*[In the Hughes RFP design the UV spectrometer was mounted to look along the spin axis rather than radially after Dr. McElroy expressed the belief that a spin rate of 5 rpm would seriously degrade the spectrometer data. While this is true for the 3 second spectral scan mode employed in Mariner, a step scan mode would be employed for Pioneer Venus in which the frequency would remain fixed during each spacecraft rotation.]

### Detailed Discussion

Stewart and Barth plan to propose UV instruments for both the orbiter and the probe bus. (They were not chosen to be on the Science Steering Group, even though submitting proposals.)

For the orbiter, a spectrometer similar to the Mariner instrument is proposed, modified for use on a spinning spacecraft. One of the outcomes of Mariner 6 and 7 was the realization that UV was a monitor for the energetics of the atmosphere and the ionosphere. Rather than just making airglow measurements, the proposed UV spectrometer experiment would make a substantial effort to understand the energetics of the thermosphere, i.e., to learn as much as possible about the energy balance in the upper atmosphere.

The wavelength region covered would start at  $1100 \text{ \AA}^0$  on the lower end to include the Lyman  $\alpha$  line; the long wavelength cutoff is a balance between scattered sunlight and the desire to measure  $\text{CO}_2^+$ . In Mariner 6 and 7 a  $4300 \text{ \AA}^0$  cutoff was used and there was a problem with scattered sunlight. In Mariner 9 the cutoff was  $3400 \text{ \AA}^0$  and there was a gain in the quality of data. In principle with the orbiter there is so much data that S/N becomes less important.

The instrument can scan the entire spectrum in 3 sec, but on a spinning satellite a different mode would be employed. One would probably step and stop the grating, obtaining a complete limb scan at a fixed wavelength. The sample time is 5 msec and a typical spin period of 15 seconds presents no problems. Scale height of the environment may be 10-15 km. A spinning mode is actually preferred to an angular pointing mode.

Considering operation over the orbit, one can look at atomic hydrogen all the way around but for everything else one would prefer to be close. The best airglow data will be obtained around periapsis (in limb observations). On the way in, one can look down into the lower atmosphere. With UV it is possible to look fairly deep into the atmosphere.

As a typical time line, there might be a span of one-half hour at periapsis when one wants as much data as possible; in the mid-region one would look at the disk of the planet, and during the rest of the orbit one would focus on Lyman  $\alpha$  radiation from space. Data storage is a critical aspect of the time line. For these measurements it is preferred to have the spin axis perpendicular to the orbit plane, or close to this.

Stewart emphasized that what he had told us was their approach to the UV measurements but that other people had other ideas. He mentioned that Mariner Venus Mercury will carry a much shorter wavelength UV instrument (provided by Broadfoot from Kitt Peak).

For the probe bus, a simple UV photometer will be proposed. Stewart would like to observe the  $\text{CO}_2^+$  line at  $2890 \text{ \AA}$ . In Mariner 6 and 7,  $\text{CO}_2^+$  is used to relate to ion density.

Stewart gave us a write-up on the Mariner 6 and 7 UV spectrometers (Applied Optics, April 1971), which is attached; there is no literature on more recent instruments. However, five Mariner 9 Ultraviolet Spectrometer Experiment reports were provided us, titled: Initial Results December 22, 1971; Mars Airglow Spectroscopy and Variations in Lyman Alpha; Photometry and Topography of Mars; Structure of Mar's Upper Atmosphere; and Observations of Ozone on Mars.



The state-of-art of spectrometers is undergoing a change, as new miniaturization techniques develop. Fastie (at Johns Hopkins) thinks he can build a UV spectrometer weighing 2 lb. The Mariner 6 and 7 description is probably quite good for present state-of-art instruments, but by the time of the Pioneer Venus orbiter, the situation will probably be quite different.

The current Ames payload allotment for the UV spectrometer of 12 lb/8 w/600 in<sup>3</sup>, which is a large increase over the original RFP values of 4.4 lb/2 w/120 in<sup>3</sup>, is believed to be quite adequate by Stewart [although the Mariner instrument is 35 lb/12 w/1420 in<sup>3</sup> (21.5 x 11 x 6 not including the sun shade)]. The UV instrument being proposed for Mariner Jupiter Saturn (1977) is only 10 x 8 x 4 in.

## Mariner 6 and 7 Ultraviolet Spectrometers

J. B. Pearce, K. A. Gause, E. F. Mackey, K. K. Kelly, W. G. Fastie, and C. A. Barth

The ultraviolet spectrometers that observed the atmosphere of Mars in July and August of 1969 consist of a planetary coronagraph and an Ebert-Fastie monochromator. The spectral range 1100–4300 Å was measured using two photomultiplier tubes, one with a cesium iodide photocathode, the other with a bialkali photocathode. These tubes were operated with fixed high voltage supplies and charge sensitive amplifiers. The instruments were calibrated by comparison with a tungsten lamp, a sodium salicylate screen, and a flowing nitric oxide cell. The instruments were able to satisfactorily reject off-axis light at a distance of 6600 km and measure the emission spectrum of the upper atmosphere 170 km above the surface.

### Introduction

The Mariner 6 and 7 spacecraft approached and flew by Mars on 31 July 1969 and 5 August 1969, respectively. Each spacecraft carried a complement of scientific instruments that included a scanning ultraviolet spectrometer. The primary purpose of the ultraviolet spectrometer experiment was to determine the composition and structure of the atmosphere of Mars by measuring the ultraviolet light emitted by the upper atmosphere and the sunlight scattered by the lower atmosphere and surface.<sup>1</sup> Results on the Mars upper atmosphere experiment have been reported by Barth *et al.*<sup>2</sup> This paper describes the design and calibration of the spectrometer and demonstrates its performance at Mars.

### Experiment Constraints

Two basic kinds of measurements were performed that can be most easily characterized by the observation geometries. The first, upper atmospheric measurements, were obtained viewing the atmosphere tangentially against the dark space background. The second, measurements of the surface pressure and reflectance, were made while viewing the planetary disk directly.

In order to detect radiations characteristic of a wide range of possible atmospheric constituents, the spectral

region 1100–4300 Å was scanned. Since the spacecraft moved at  $\sim 7$  km sec<sup>-1</sup> relative to Mars, a spectral scan was made each 3 sec so that at least one measurement would be obtained every 21 km, the nominal atmospheric scale height. A study of the expected atmospheric features showed that a spectral resolution of 20 Å was sufficient to identify them, but a sensitivity of 100 R was required (a rayleigh is equal to  $10^3$  photons cm<sup>-2</sup> sec<sup>-1</sup>). The ability of the instrument to reject off-axis light from the very bright planetary disk during the upper atmospheric measurements was critical to this part of the experiment. A high dynamic range was required to accommodate these weak signals and also the intense ( $10^4$  R) signals expected during the surface pressure and reflectance measurements. To satisfy these constraints an Ebert-Fastie scanning monochromator with dual photomultiplier detectors was used in the focal plane of a reflecting planetary coronagraph.

### Planetary Coronagraph

The coronagraph, described by Fastie,<sup>3</sup> uses a 0.25-m focal length spherical primary mirror that forms an off-axis image of the atmosphere in an occulting slit plane (see Fig. 1). This mirror is aluminized and overcoated with MgF<sub>2</sub> in order to provide high reflectivity throughout the spectral range, as are all the optical surfaces in the instrument. In front of the mirror is a multiple baffle system (see Fig. 2) designed to prevent light from the planet's surface from striking the primary directly. A baffled secondary mirror transfers the atmospheric image, passed by the occulting slit, to the entrance slit of the monochromator. Also in the plane of the occulting slit are two near infrared sensitive photodiodes used as planetary limb sensors to control the dynamic range of the detector system. Figure 3 shows the image, formed by the coronagraph, of the monochromator entrance slit and the limb sensors in a

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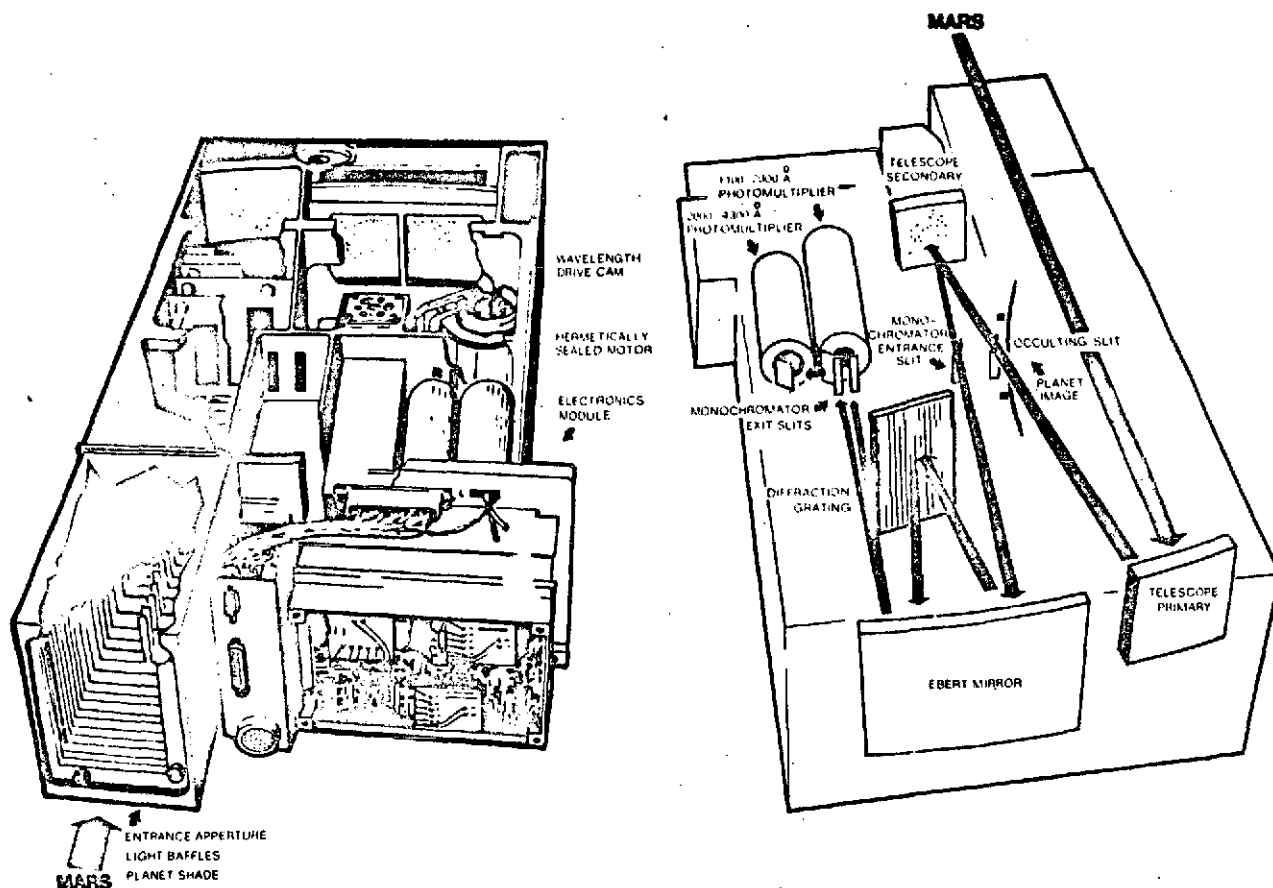


Fig. 1.  
A ghost view of the Mariner 6 and 7  
ultraviolet spectrometer showing the location  
of various parts and a schematic ray path.

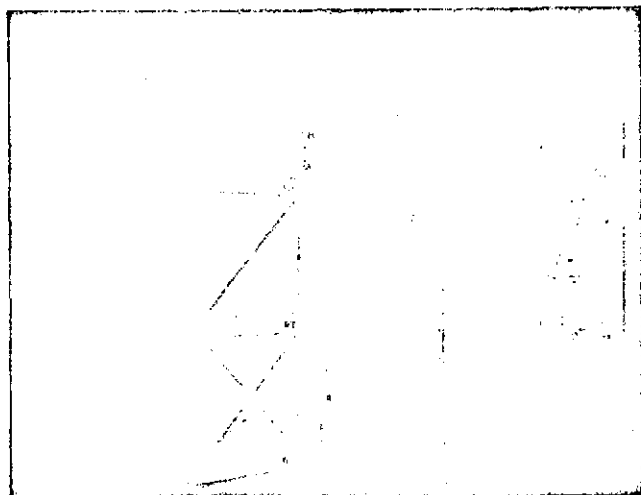


Fig. 2. The Mariner 6 and 7 ultraviolet spectrometer. The detector and electronics assembly is at the bottom in the foreground with connectors. Above is the viewing port with the coronagraph baffles showing. Visible in the main housing are additional baffles above and the wavelength drive cam in the monochromator below.

plane perpendicular to the optical axis and containing the planet's center.

### Ebert-Fastie Monochromator

The Ebert<sup>4</sup>-Fastie<sup>5-7</sup> monochromator uses a plane diffraction grating and a single spherical mirror. The monochromator forms a spectrum of images of the entrance slit in the exit slit plane (see Fig. 4) for each diffraction order. A separate exit slit was provided for each of the two detectors. In operation, the position of the spectral images with respect to the exit slits is controlled by cyclically scanning the grating.

The grating is a 2160-lines  $\text{mm}^{-1}$  replica, blazed at 3000 Å. The first order is scanned so that the spectral range from 1900 Å to 4300 Å is covered in first order as seen by one of the two exit slits, and the range from 1100 Å to 2100 Å in second order by the other. The efficiency of a typical grating is shown in Fig. 5. A scan is made from low to high wavelengths in 2.82 sec and rapidly returned to low in 0.18 sec. The 56-mm by 64-mm ruled area of the diffraction grating subtends the limiting aperture of  $f/4.2$ . The spectral resolution of the instrument, which is a slowly varying function of

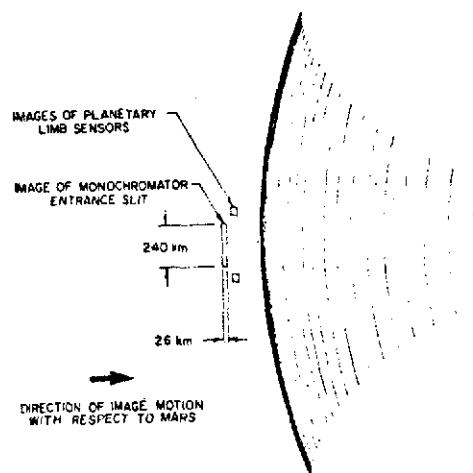


Fig. 3. The Mars atmospheric observation geometry just prior to a limb crossing.

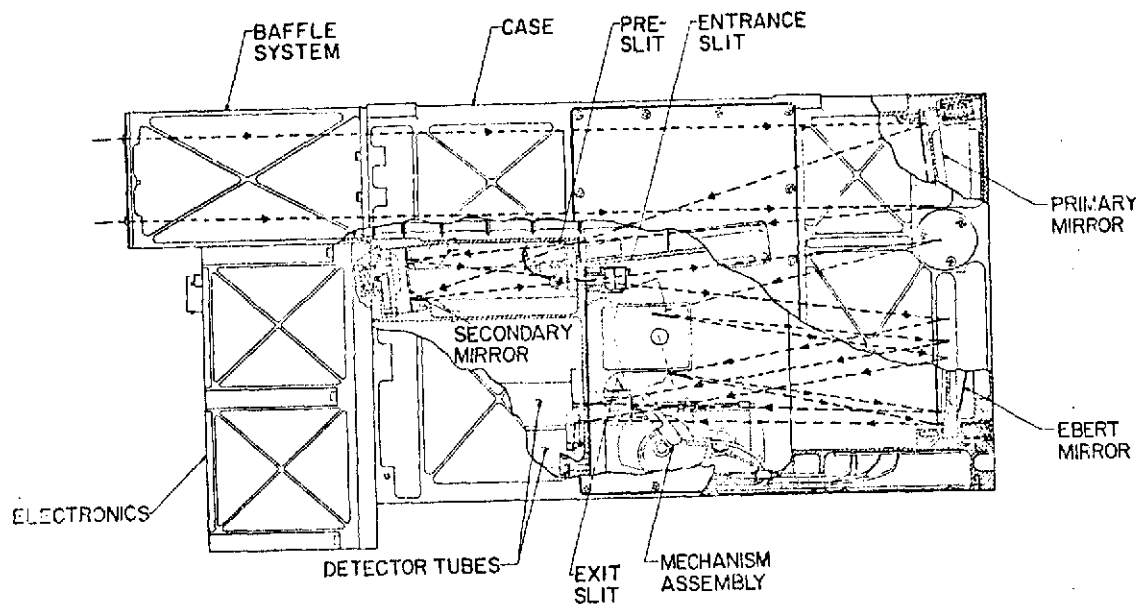


Fig. 4. A plan view drawing of the instrument with the extreme rays shown.

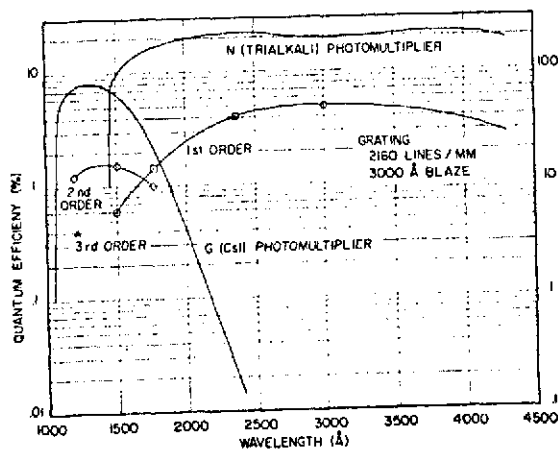


Fig. 5. Relative efficiency of gratings and photomultiplier tubes of the types used in the Mariner 6 and 7 ultraviolet spectrometers vs wavelength. Measurements were performed under simulated instrument conditions (symbols) and used for normalization of manufacturers specifications (lines).

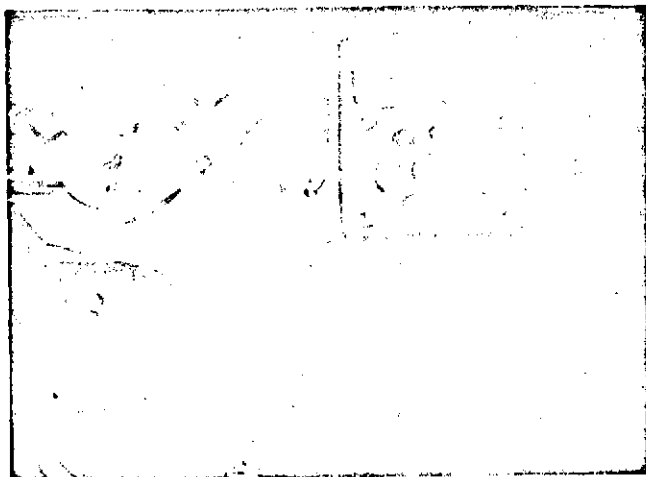


Fig. 6. Scan mechanism assembly showing grating, cam, and follower and the magnetic sensor for the fiducial marker. The motor and planocentric drive are beneath the cam.

wavelength, is  $20 \text{ \AA}$  at  $2950 \text{ \AA}$  in the first order as limited by the slit width.

The grating is rotated through about  $16^\circ$  during each spectral scan. The motion is controlled by a cam and follower driven by a two-phase hysteresis synchronous size 11 motor (see Fig. 6). The motor is driven by 300-cycle square wave power derived by counting down the 2400-Hz spacecraft power. This results in a pinion speed of 9000 rpm which is geared down to drive the cam at 20 rpm. To ensure proper lubrication and at the same time eliminate danger to the optics, the motor and gear train are hermetically sealed. The cam is driven by the ring gear of a planocentric gear set. The pinion of the planocentric pair is sealed to the motor housing with a bellows (see Fig. 7). The planocentric gear teeth that must run in hard vacuum are Nitroloy 135 M. All bearings running in hard vacuum are non-lubricated Bar Temp bearings.

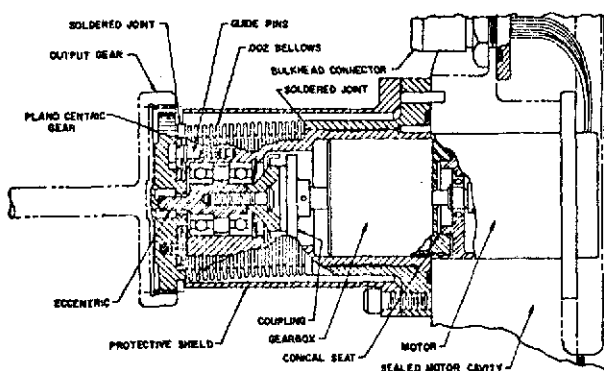


Fig. 7. Planocentric drive assembly showing the synchronous motor, gear box, and eccentric that drives the planocentric pinion. The cam is attached to the shaft of the output gear.

## Detectors and Electronics

Two photomultiplier tubes are used as detectors. The one sensitive to light in the  $1900\text{--}4300 \text{ \AA}$  spectral region is offset from its exit slit by a reflecting periscope; and the other, for second order light in the range from  $1100 \text{ \AA}$  to  $2100 \text{ \AA}$ , is mounted directly behind its exit slit (see Fig. 4). The photomultiplier tubes used are of the end window, semitransparent, high work function photocathode variety manufactured by EMR. They have an in-line venetian blind dynode structure and are, in this case, operated with the anode near ground potential. The longer wavelength sensitive tube used in the  $1900\text{--}4300 \text{ \AA}$  range, the N channel, is a model 541N-05M which has a bialkali photocathode and a sapphire window. The other tube, sensitive from  $1100 \text{ \AA}$  to  $2100 \text{ \AA}$ , the G channel, is a model 541G-08 using a cleaved lithium fluoride window with a cesium iodide photocathode. The spectrum of light scattered from the surface and lower atmosphere is approximately that of the sun, an  $\sim 5000 \text{ K}$  blackbody. In order to measure light in the  $1100\text{--}1800 \text{ \AA}$  region it is necessary that the detector be insensitive to light at wavelengths longer than  $\sim 2100 \text{ \AA}$  since the diffraction grating diffusely scatters a small fraction of this enormously brighter source. This rejection characteristic is a consequence of the high work function of the cesium iodide photocathode. The relative sensitivity of these photomultiplier tubes is shown in Fig. 5.

Figure 8 is a block diagram showing the operation of the electronics system. High voltage for the operation of the photomultipliers is supplied by independent ac to dc converter multipliers powered by the spacecraft's 2400-Hz power bus. The voltage supplied to the short wavelength photomultiplier is fixed; that supplied to the other has two selectable values. This was done so that the gain of the multiplier structure, which varies with the voltage supplied, could be changed during the experiment to accommodate the wide range of expected light levels. The appropriate voltage is selected automatically by the limb sensors. When the light level, as determined by either of the planetary limb sensors, exceeds a predetermined level as detected by individual Schmidt trigger circuits, the high voltage to the longer wavelength sensitive photomultiplier tube is reduced to a value such that its gain is lowered by a factor of  $\sim 1800$ . Thus spectra in the  $2000\text{--}3000 \text{ \AA}$  region, that most sensitive to ozone absorption in the Hartley bands, can be recorded without saturation. The triggering of the Schmidt circuits is indicated by pulses in the shorter wavelength channel. Likewise, when the light level measured by the limb sensors falls below a second level, the high voltage to the first photomultiplier is restored to its initial value.

During the 2.82 sec when the monochromator is being scanned, a signal proportional to the photomultiplier tubes anode current, and thus proportional to the detected light intensity, is measured. The output current is integrated and amplified by a charge sensitive amplifier, and its output is then presented to an analog-to-digital converter. This converter consists

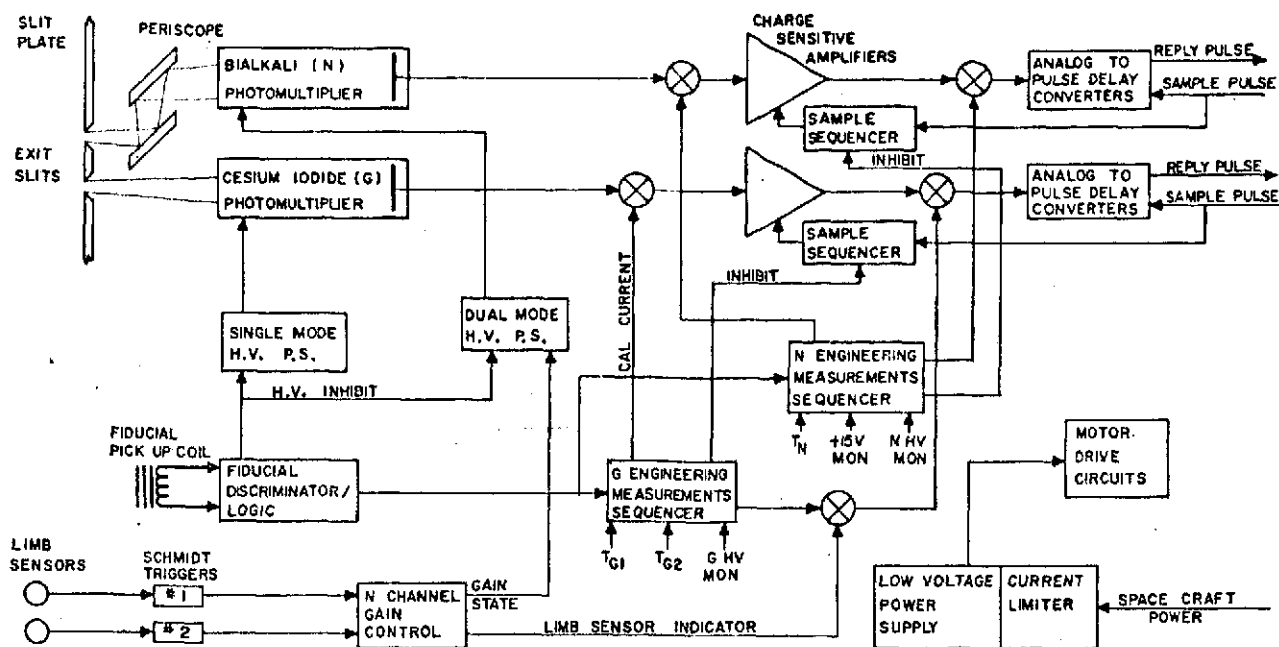


Fig. 8. Block diagram of the detector and electronics system.

of an analog-to-pulse delay converter in the instrument and a gated counter in the spacecraft data system. Figure 9 is a schematic diagram of one of the channels. Each photomultiplier tube's output is integrated and read at 5-msec intervals. The readouts occur alternately and symmetrically, thus an instrument reading is obtained each 2.5 msec. At each readout commanded by the data system, the following sequence occurs:

- (1) the voltage on the capacitor is applied to the high sample and hold amplifier (switch 1 in Fig. 9);
- (2) the photomultiplier tube input circuit integrating capacitor is shorted for 100  $\mu$ sec (switch 2);
- (3) a measure of the voltage across this capacitor is transferred to the low sample and hold amplifier (switch 3); and
- (4) the difference analog signal (high-low) is transferred to the final sample and hold circuit where it remains stored until an analog-to-digital conversion is initiated by the following read command (switch 4).

This differential method is used to negate the effect of the transients produced while shorting the integrating capacitor and the offset of the high input impedance FET emitter follower circuit used to isolate the integrating capacitor from the sample and hold amplifiers.

At a rate of one sample per channel per 5-msec interval, approximately nine samples are taken per spectral resolution element at full width. This number is independent of the diffraction order observed. Thus, every 3 sec a spectrum is produced consisting of 600 total points from each of the two detectors. Thirty-six of the samples are devoted to fiducial period measurements and 564 to spectral measurements. Since the spacecraft data automation subsystem digitizes the output of the analog-to-pulse delay converters to eight

bits, a total instrument bandwidth of 3200 bits  $\text{sec}^{-1}$  is required.

At the beginning of the 0.18-sec flyback portion of the wavelength scan, a small permanent magnet attached to the grating drive cam passes through the gap of a pickup coil fork. The resulting pulse is used as a wavelength fiducial (see Fig. 8). The following sequence is thus initiated (note: certain of the following items are referenced by capital letters in Fig. 9):

- (A) the high voltage supplied to both photomultiplier tubes is reduced to a low value;
- (B) the amplifier offset is measured while shorting its input to ground for twelve 5-msec sample periods;
- (C) a known current is injected parallel to the photomultiplier anode by means of a calibrated resistor

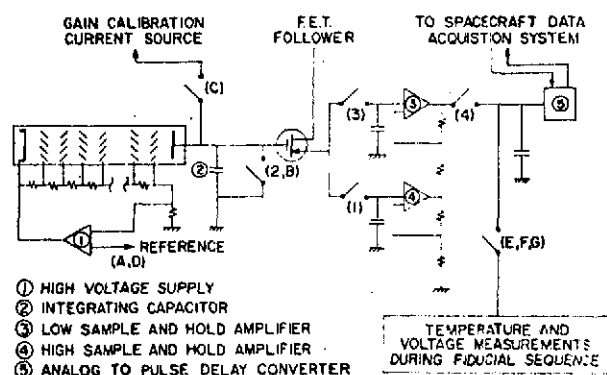


Fig. 9. Electrical schematic for a single detector channel. The letters and numbers in parentheses correspond to functional descriptions in the text.

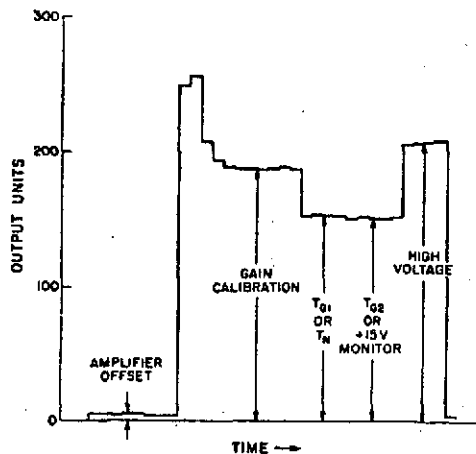


Fig. 10. The spectrometer output during a fiducial sequence.

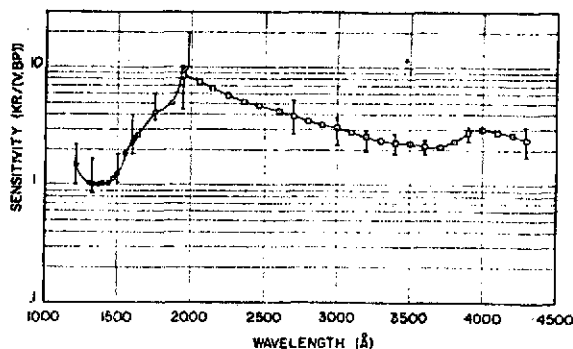


Fig. 11. The sensitivity of the Mariner 6 ultraviolet spectrometer. The points indicated by the  $\circ$  are the G channel sensitivities in kilorayleighs per volt per bandpass (nominally 10 Å). Those indicated by the  $\square$  are the N channel high gain sensitivities in kilorayleighs per volt per bandpass (nominally 20 Å).

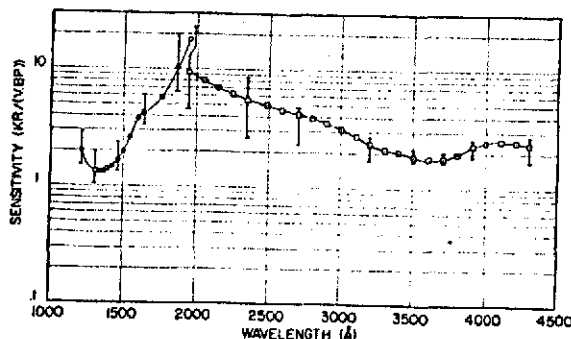


Fig. 12. The sensitivity of the Mariner 7 ultraviolet spectrometer. The points indicated by the  $\circ$  are the G channel sensitivities in kilorayleighs per volt per bandpass (nominally 10 Å). Those indicated by the  $\square$  are the N channel high gain sensitivities in kilorayleighs per volt per bandpass (nominally 20 Å).

operated from a regulated voltage for twelve samples;

(D) the high voltage is turned back on;

(E) during the turn-on transient, two temperature sensors are monitored, one by each channel, and their outputs presented the analog-to-pulse delay converters for four samples;

(F) the voltage level of the common, regulated, low voltage power supply in the case of the 1900–4300 Å (N) channel, and a second temperature in the 1100–2100 Å (G) channel is telemetered for four samples; and

(G) a voltage proportional to the now stable high voltage is presented for four samples. At this time, operation returns to the normal mode of telemetering the photomultiplier output. An example of the telemetry data during the fiducial period is given in Fig. 10.

The motor and driver circuit requires 4.1 W for operation. This combined with the 10-W requirement of the sensor electronics yields a total power consumption of 14.1 W.

### Mechanical and Thermal Design

The six elements in the optical system are most sensitive to potential bending of the optical housing. Bending can cause a wavelength shift, loss of efficiency, or a total loss of signal. Sufficient thermal gradients across the case in the directions of thickness or width would cause one or more of these forms of degradation. To minimize the probability of experiencing a loss of performance under any of the anticipated environmental conditions, the instrument was machined from a single block of aluminum. This technique resulted in gradients of  $\sim 2^\circ\text{C}$  under flight conditions. Gradients of this magnitude are easily accommodated by the optical system with no detectable effects on performance.

Structurally, the one-piece case proved to be rugged and reliable and had the advantage that the optical alignment was not subject to variations in torque applied to a screw, or to creep at joint interfaces during mechanical qualification and handling.

### Calibration

The sensitivity in the 2800–4300 Å region was measured by recording the instrumental response to a tungsten strip lamp, of the type calibrated by the National Bureau of Standards (NBS) as a standard of spectral radiance.<sup>8</sup> The instrument viewed a smoked magnesium oxide screen illuminated by the light from a 2-mm by 2-mm area of this lamp using an  $f/20$  quartz lens of accurately known area. This lamp was later compared with an NBS calibrated lamp and the resultant radiance used to reduce the instrument data. Calibrations identical in technique but using different lamps and screens were performed in two different laboratories. The results were confirmed within the accuracy of the measurements. The resultant sensitivity in this range is presented in Figs. 11 and 12.

The sensitivity of the instrument was also measured at several wavelengths between 1216 Å and 2900 Å by noting its response to a collimated beam from a

monochromator illuminated with a discharge lamp. The intensity of this beam was measured using a raster scanned reference photomultiplier tube. This tube was compared to the response of a flowing nitric oxide ionization cell at 1216 Å and 1300 Å. The sensitivity of this tube at other wavelengths was determined relative to the sensitivity of sodium salicylate. This tube has been recently (April 1970) calibrated by comparison with a calibrated photodiode at NBS.<sup>9</sup> A prototype instrument was calibrated in the above manner and also calibrated in the Vacuum Optical Bench (VOB) facility at the Goddard Space Flight Center. This calibration, utilizing the above and other independently calibrated reference tubes, confirmed the method used on the flight units. The sensitivity of the instruments in this region is also presented in Figs. 11 and 12.

During these calibrations the data were received by a specially constructed spacecraft data system simulator and subsequently recorded on digital magnetic tape.<sup>10</sup> This was done so that a signal path as nearly identical as possible to that in flight could be used and to provide a library of calibration data that could be directly compared with flight data.

### Instrument Performance

The Mariner 6 and 7 spacecraft, from which the observations were made, have been described.<sup>11</sup> The instrument scan platform was maneuvered in such a way that two complete limb crossing sequences were obtained on both Mariner 6 and 7 (see Fig. 3). The image of the spectrometer entrance slit was moved from high in the atmosphere down across the limb with the long dimension of the slit tangent to the limb at its center and then onto the surface for each sequence.

Figure 13 is a Mariner 7 spectrum taken when the spacecraft was 6593 km from Mars and the spectrometer was viewing the atmosphere tangentially, the optical axis being 170 km from the surface at its closest point. In addition to the emission features identified in the spectrum, there is a small amount of off-axis scattered light evident in the 2800–4300 Å region. Had the coronagraph been unable to suppress the scatter to this level, the important  $\text{CO}_2^+$  and atomic oxygen measurements would have been lost. The spectral resolution of the instrument is apparent from the width of the second and third order 1216-Å, hydrogen Lyman- $\alpha$  features. It can be seen that the transmission of several independent measurements per spectral resolution interval allows easy identification of such a feature in the presence of impulsive noise such as the feature at an apparent wavelength of 1245 Å. A measurement of the Lyman- $\alpha$  line, indicating the instrumental profile, is given in Fig. 14 and compared with the theoretical profile. The differences are not due to deviations in shape but rather to the statistical uncertainties in each individual measurement.

A Mariner 7 spectrum of the lower atmosphere and surface emissions is given in Fig. 15. This spectrum was taken with the N channel in the lower of its two gain states as indicated by the position of the high

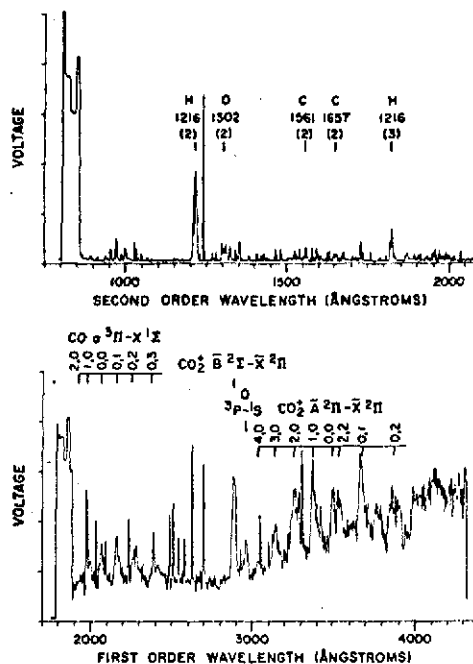


Fig. 13. The spectrum of the upper atmosphere of Mars in the 1100–4300 Å region as measured by Mariner 7. The numerals in parentheses indicate the diffraction order.

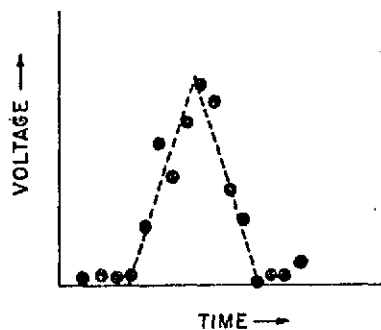


Fig. 14. An expanded view of the instrument response to an atomic line source (dots) and the theoretical profile (dashes).

voltage monitor step on the fiducial. As such, the very bright emissions are measured with a high signal-to-noise ratio. Evident are many features of the solar Fraunhofer spectrum which is diffusely reflected with an efficiency which varies slowly with wavelength. A portion of the spectrum above 3500 Å was intentionally placed off-scale so that the region from 2400 Å to 3000 Å could be emphasized. This region, unavailable to earth-based measurements, provides a particularly sensitive measure of ozone. Weak emission lines due to hydrogen and oxygen in second and third orders are seen against the much stronger scattered sunlight contribution in first and second orders in the 1800–2400 Å region in the G channel.

During the Mariner 6 and 7 encounters, 24 spectra were obtained of the upper atmosphere between 100 km and 220 km, and 475 spectra were obtained of var-



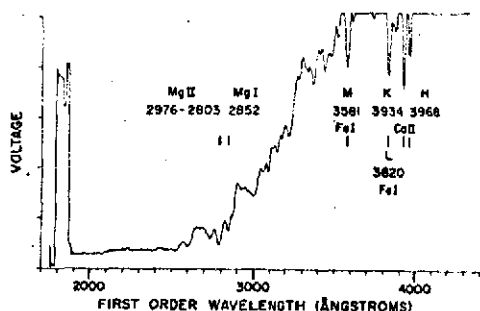
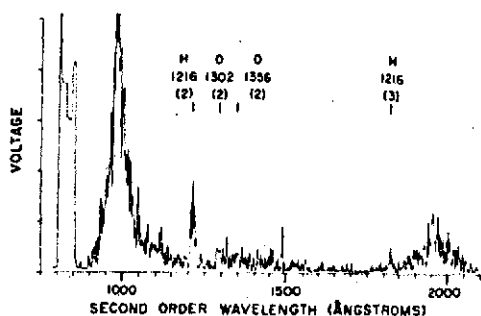


Fig. 15. The ultraviolet spectrum of Mars as measured by Mariner 7 while viewing the planet's disk. The numerals in parentheses indicate the diffraction order.

ious locations on the disk of Mars. In addition, the Lyman- $\alpha$  sky brightness was measured with these instruments during the weeks following the encounter.<sup>12</sup> During these observations, the ultraviolet spectrometers

performed flawlessly, producing spectra containing far more information than had been anticipated.

The authors wish to acknowledge the efforts of L. R. Dorman and G. McNutt for their efforts culminating in a successful experiment at Mars.

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## PIONEER VENUS SCIENCE TRIP REPORT

### 2.2 YORK UNIVERSITY, 27 SEPTEMBER 1972

#### Introduction and Summary

A visit was made to York University in Toronto, Canada, on 27 September 1972 to discuss the UV Fluorescence experiment with Dr. Robert Young.

This experiment is currently listed as part of the nominal payload for the probe bus. It is a new experiment which did not appear in the RFP and on which we had no information other than a brief one paragraph statement of objectives in the SSG report. Papers by T. G. Slanger at the Stanford Research Institute on UV Fluorescence were referenced in the SSG report. Slanger was contacted and referred us to Dr. Young as the person to see regarding details of the experiment.

#### Key facts learned in the discussion:

- The unique feature of this experiment is the resonance radiation lamp which Young has developed.
- Young wants to go in with a co-investigator who would build the experiment, with Young providing only the lamp and its housing. (He cannot get funding from the Canadian Government and doesn't have the facilities needed to build and test the experiment.)
- There will be two rocket launches, one this spring and one the following winter testing the instrument. (SSG feels rocket tests are essential before the experiment can be accepted.)
- The experiment requires a half-meter boom (presumably not included in the weight allotment) with a 2 inch diameter grating mounted at the end.
- Mounting is rather critical. The boom must be perpendicular to the velocity vector, within a few degrees.
- The Ames payload numbers for this instrument seem quite reasonable to Young.

Detailed Discussion

Young had just received the AFO and felt that if he were chosen as an experimenter he would have a hard time performing, and a hard time financing, although they had the critical hardware pretty much built. Last spring he went around looking for a cooperative experiment; the net effect was that no one wanted to get involved because they were involved in their own things. The only person he hadn't contacted yet was Bill Fastie at Johns Hopkins.

The objective of the experiment is to measure atomic O and CO, one of which is a stable species. The chemical process has been studied in the laboratory, and the instrument has been shot in a rocket, but there has not yet been a successful rocket test. For reactive species like atomic oxygen, mass spectrometers have a sampling problem; this experiment is a back-up to the mass spectrometer. The experimental procedure here is to emit resonance radiation which is preferentially absorbed by one species, and measure the resulting back-scatter. This device has the advantage that samples are taken in the free stream, and it gives a point measurement. The mass spectrometer is a point measurement with high sampling error. Most optical experiments are path experiments.

For rocket experiments a prototype has been made with no attempt to minimize size and weight. The experiment requires a boom with a grating on the end. The only unique thing in the instrument is the lamp. There will be two rocket launches from Fort Churchill with the full experiment. It will be coordinated with mass spectrometer measurements. The boom is to be engineered by the Canadian Rocket Branch.

There will be one rocket test this spring, and one next winter, which might be launched from White Sands. The only thing that Young feels needs

testing is the lamp itself. The problem is that Young doesn't have the funds to make these lamps to use in rocket tests. He has had many offers of launch opportunities.

The tube is a tuned-line oscillator. The oscillator operates at 200 Mc, but is much more efficient at higher frequency, and a new design will operate at 1000 Mc. SRI has had no experience with this device. Slanger, in his experiments, has used a different kind of lamp in measuring atomic oxygen.

For the purpose of this experiment, a clean spectral line is needed. It operates at  $1300\overset{\circ}{\text{A}}$  where there are 3 oxygen lines closely spaced (a few  $\overset{\circ}{\text{A}}$  apart). The lamp needs to be intense but optically thin; otherwise there is much distortion.

A half-meter boom is required. The experiment must be mounted perpendicular to the velocity vector of the atmosphere as it moves by the vehicle. There is a Doppler effect, the faster this gas moves, the greater the line shift. At Mach 1 the shift is slight, at Mach 8 it is large. One needs to scan this region. Young likes a spinning motion, which gives a useful modulation. Configuration of the experiment is shown in Figure 1.

With regard to the Ames payload numbers, a weight of 3 lbs., if it excludes the boom, is realistic. The grating weighs a few ounces. The power requirement is more or less realistic. He can't see the power going under 1 watt although it might possibly get down to 1 watt. A volume of 120 cu. inches seems no problem.

Young needs 10 numbers per sample to 1% accuracy (i.e., 5 bits); this means 50 bits/sample, without housekeeping functions (but this is a short experiment and the housekeeping could be done prior to the measurements).

Young could provide a prototype instrument by December if given modest support. But engineering and reliability tests could in no way be done at

(Velocity Vector  $\perp$  to Plane of Paper)

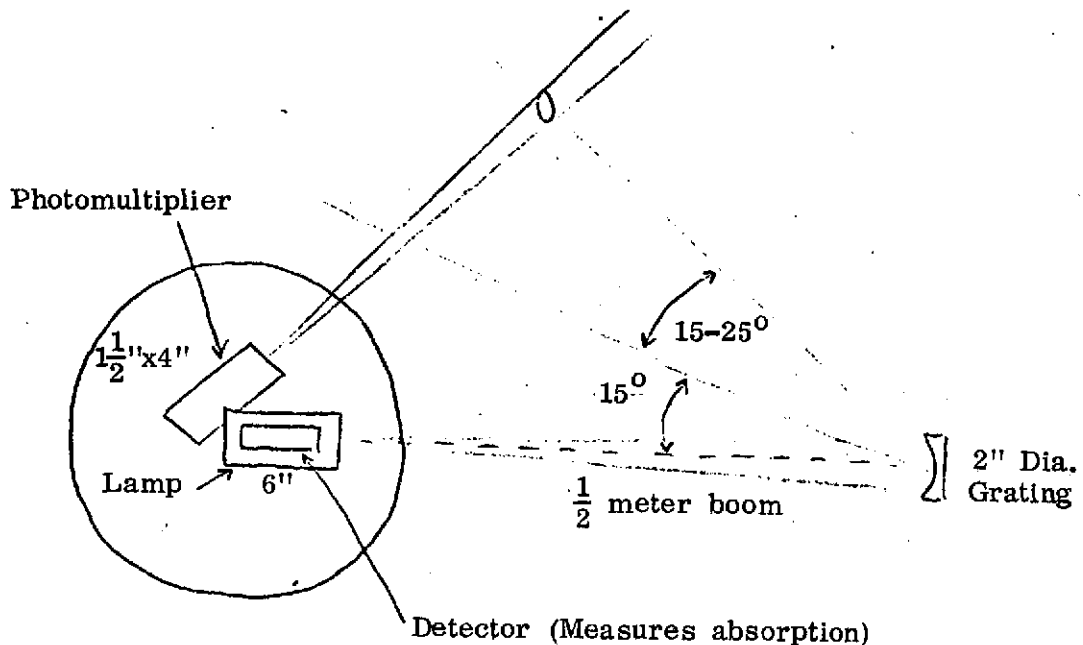


FIGURE 1. Configuration of UV Fluorescence Experiment.

York University. They simply don't want the experiment. They don't have the people. All funding at York comes from the Canadian Government. It would cost 100,000 dollars and Young couldn't even get 50,000 dollars. There is no space agency in Canada. Young does get some support from the Canadian National Research Council, and has a 20,000 dollar contract with the U.S. Army.

Young wants to go in with a co-investigator, who will involve Young as principal scientist or consultant while he builds the equipment. Barth would go in, but then would have the problem of having to select between the UV Spectrometer and the UV Fluorescence experiment and doesn't want to be in that position. Young would like to provide the lamp and its housing.

Attached are descriptions of the resonance lamp, and of the rocket test configuration.

## Low Power, Sealed, Optical Thin Resonance Lamps

by

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Centre for Research in Experimental Space Science

York University, Toronto, Canada

The use of resonance absorption and fluorescence is becoming prevalent in chemical kinetic research. This would have arrived earlier if the species of interest were those to which metallurgists had long applied this technique. For maximal sensitivity, the radiation used must peak strongly at the resonance absorption line of the species to be measured. If only absorbable radiation is used, then direct detection of the transmitted or fluoresced radiation without the intervention of filters or dispersal devices is possible.

Most lamps used to produce resonance radiation of atoms derived from gaseous compounds utilize an A-C electrical discharge in a low pressure gas which flows away from the emission direction. Since dissociation must coincide or proceed excitation, it is difficult to obtain bright resonance lamps without self absorption. Evidently atoms should exist only in the excitation region, and there be excited as efficiently as possible.

Although non-flowing, sealed resonance lamps have considerable convenience, and are essential in some circumstances (rocket application), they are difficult to control since the discharge

interacts with the walls of the lamp to either remove or provide constituents. This is particularly true for oxygen.

A successful sealed lamp which produces the atomic oxygen resonance lines at 1304, 5, 6, will be described as a prototype of other lamps emitting resonance lines of atomic nitrogen, hydrogen, and molecular resonance emission from CO and NO.

#### The Lamp Design and Operation

Figure 1 shows the lamp body. Side ovens contain a source ( $\text{Mn O}_2$ ) and sink (Ur) of oxygen which are constrained by frittered glass. A central thin tube permits the insertion of a fine wire which, when the outer wall of the lamp is covered with a conducting point, constitutes a segment of a coaxial transmission line for the high frequency (200 Mhz) electrical excitation which powers the lamp discharge.

Figure 2 is schematic of the exciter-oscillator and Figure 3 is a photograph of the completed assembly.

The lamp is filled with 1 torr of He after the usual vacuum pump down procedures and after processing the uranium getter. Figure 4 shows the spectrum of the lamp, which is dominated by the atomic oxygen lines between 1200 and 2000 Å, when the  $\text{Mn O}_2$  is at its proper temperature. This lamp is suitable for direct viewing with a solar blind photomultiplier.

Figure 5 indicates how each element of the triplet changes intensity as the temperature of the  $\text{Mn O}_2$  is increased until the lines

become optically thick, at which point the spectra of Figure 4 was recorded. By measuring a) the ion current produced in a nitric oxide cell attached to the lamp window, b) the fractional absorption of the resonance and lines due to this nitric oxide absorption, and using the literature data on the efficiency of ion production in NO at 1306, it was determined that an optically thin lamp emitted approximately  $10^{13}$  photons/sec in a cone with a half angle of approximately  $20^\circ$ .

Figure 6 shows how the intensity of the oxygen triplet varies when the lamp is operated as a flow lamp (so that the concentration of molecular  $O_2$  could be measured) and, for comparison, a similar curve for a microwave excited flow lamp. Unfortunately the data does not overlap, but it is clear that at comparable optical depths (as determined by the relative intensity of the triplet structure) the coaxial lamp would be less than an order of magnitude weaker than the microwave excited lamp. Almost this whole difference is accounted for, not by the difference in excitation power (5 watts vs 100 watts of microwave power) but by the higher frequency (2000 Mhz) of the microwaves. At fixed excitation voltage on the central wire the intensity of emission vs frequency is approximating fit by  $I = a(1 - \frac{f}{f_0})$  with  $f_0 \approx 300$  Mhz. Hence should a transistor be available which could produce about 5 watts of power at a frequency higher than 200 Mhz, a more efficient lamp could be constructed (but only by about a factor of 4 at most).

It should be noted that the lamp is self starting even when



26 volts is the highest supply voltage. This is necessary if the lamp is to be modulated (for example to isolate it from background radiation) and occurs because of the high field near the central glass electrode caused by the concentric geometry. Starting is also facilitated by the necessity that the standing wave in the coaxial line, of which the lamp is part, has an anti-node at the lamp. When breakdown occurs, the frequency of the lamp changes in accord with the new standing wave length, since the lamp now has a finite impedance. This frequency shift helps match the lamp impedance to the oscillator impedance.

The particular mounting of lamp and oscillator shown in Figure 3 has been flown in a rocket and has satisfactorily withstood the high environmental stress of such a situation.

A. Dimensions and materials

CaO

fig. 1

constrict. to stop glass work

MnO<sub>2</sub>

filling tube

(all dim. in mm)

**FIGURE 1.**

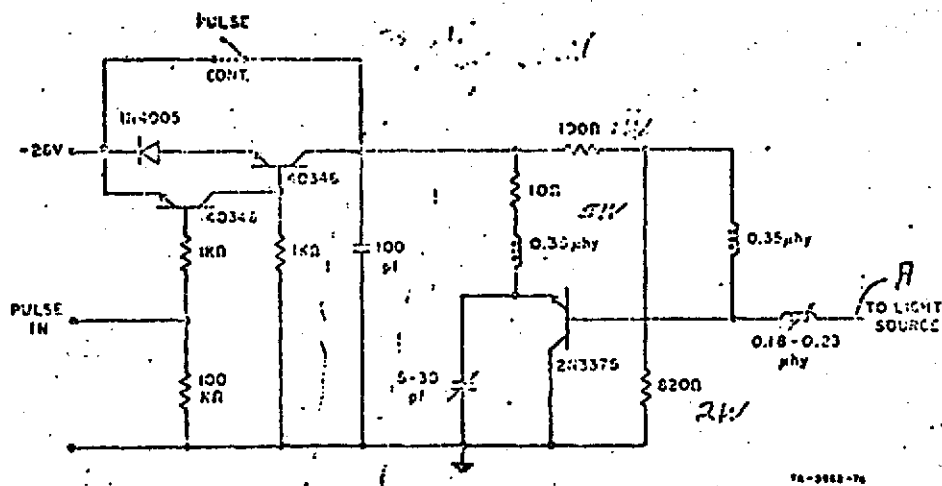
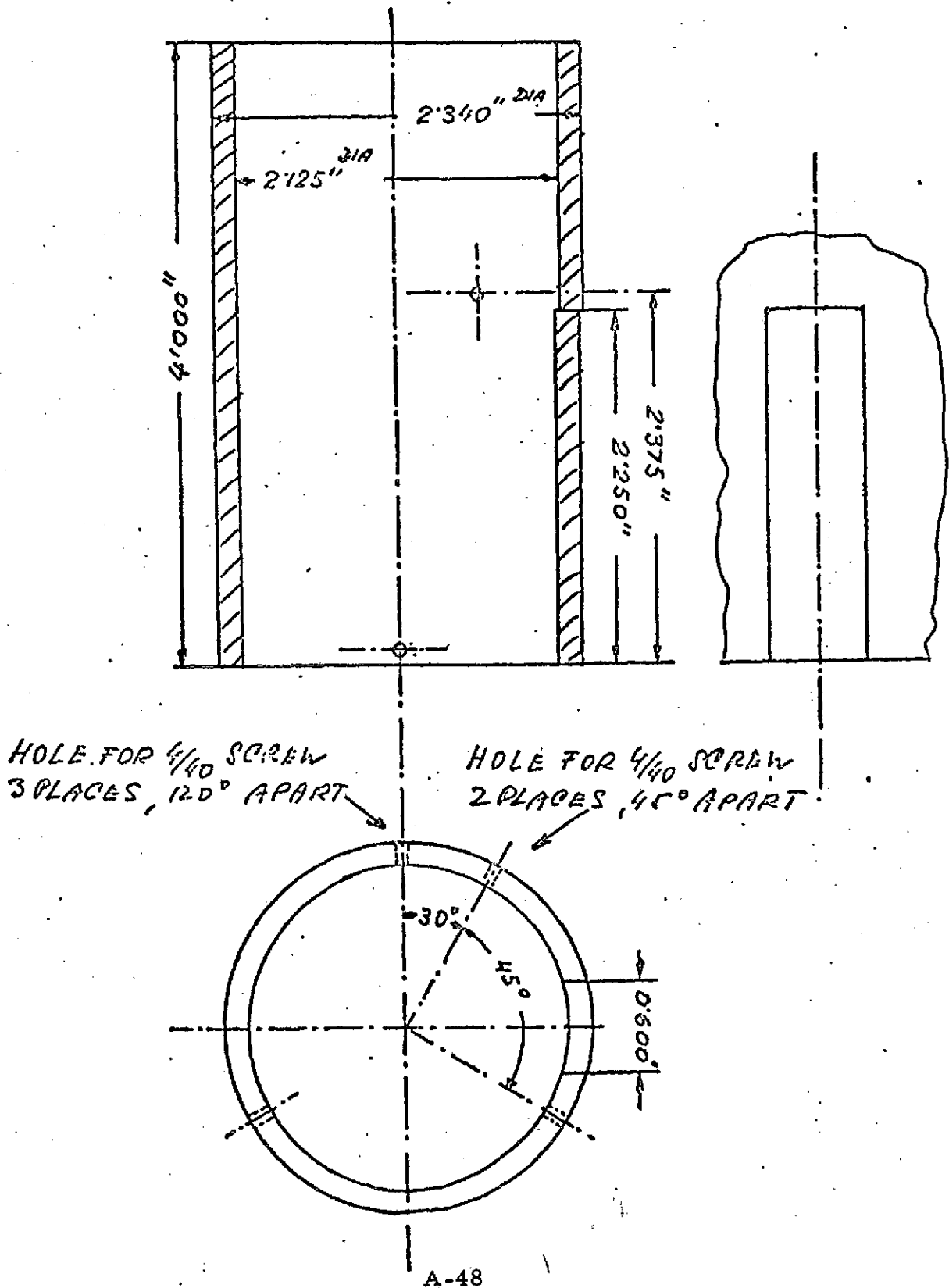


FIGURE 2.

# LAMP CASE

MATERIAL - ALUM



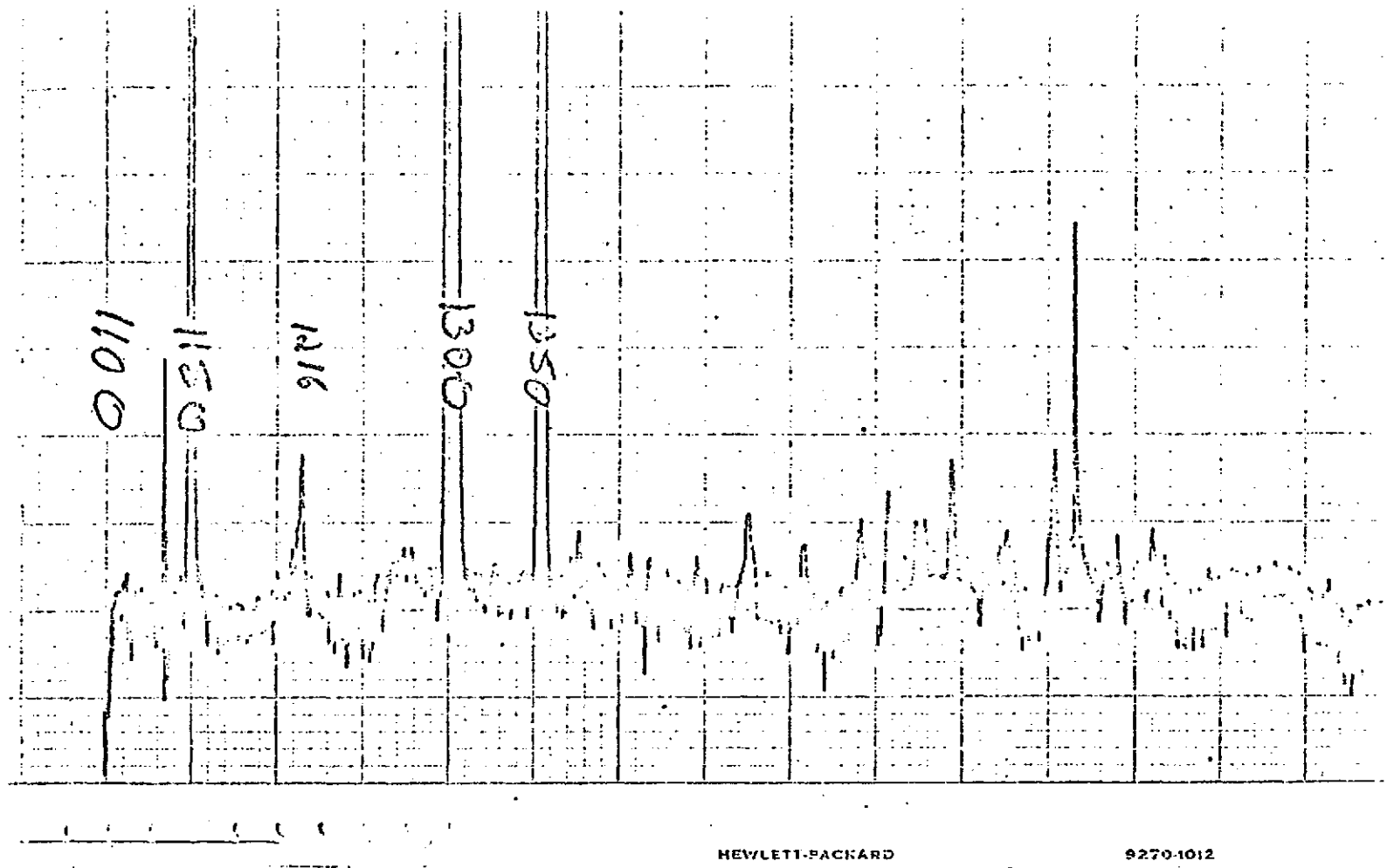
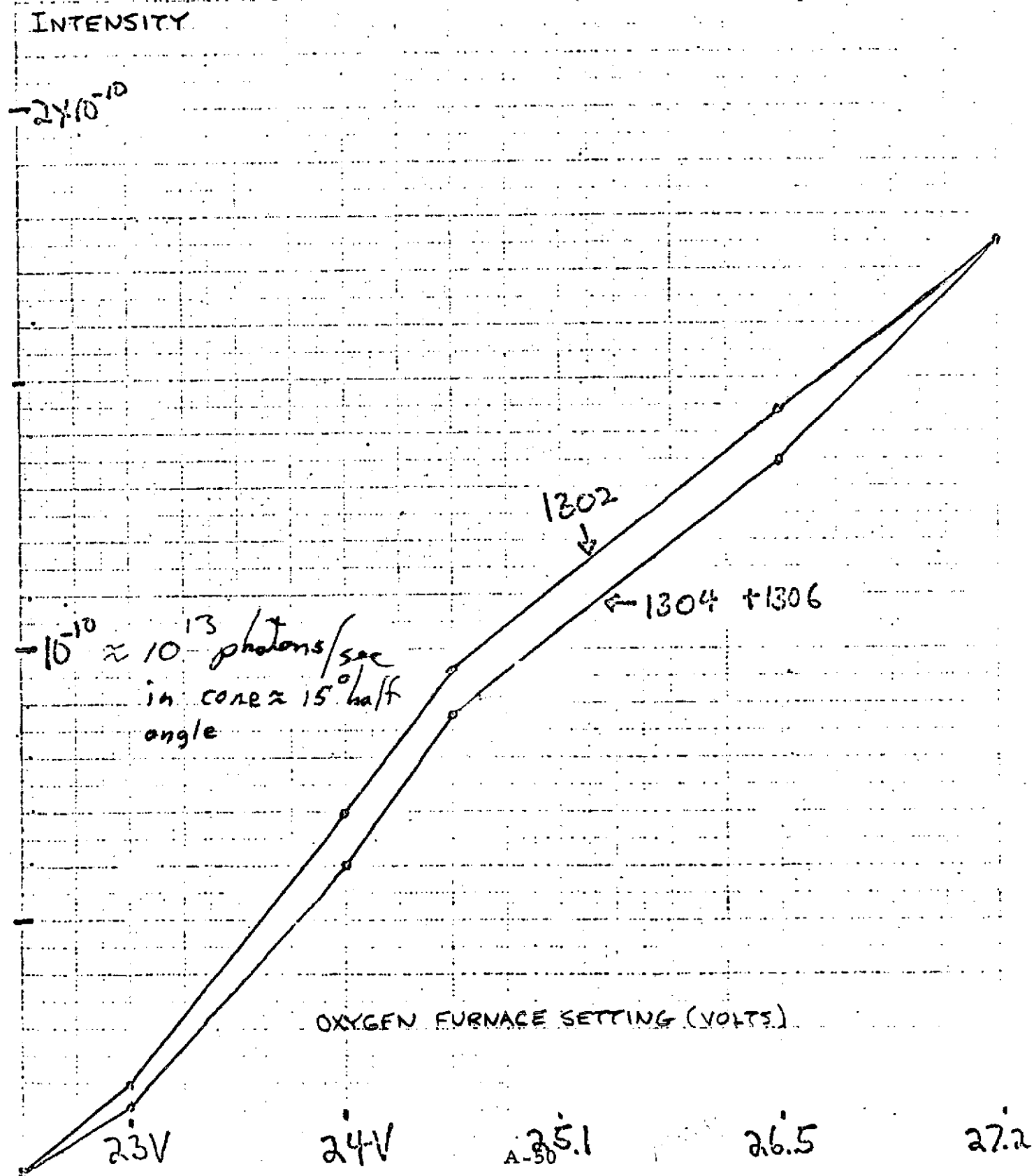


Figure 4

Figure 5



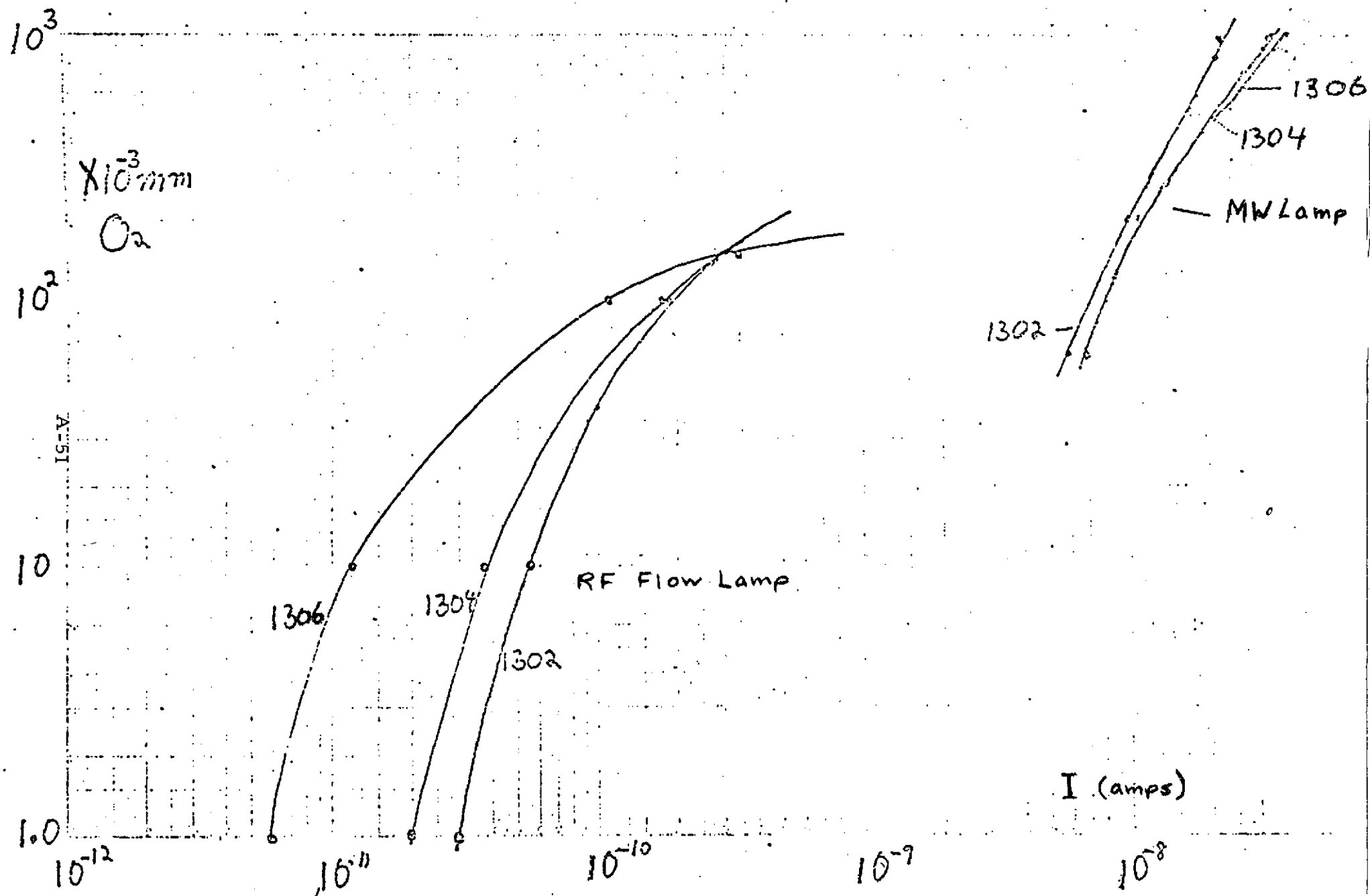


Figure 6

June 23, 1972

J. Ridgeway, Esq.  
Space Research Facilities Branch  
National Research Council of Canada  
Ottawa 7, Ontario

Dear John:

Re: AMD-IIIB-66

Our more or less identical experiments for IIIB 66 and VB 34 are now taking definite shape. I thought you would appreciate some more positive information.

The oxygen probe will employ resonance absorption instead of fluorescence. To this end, a boom will place a mirror 2 feet from the rocket skin, to reflect radiation from the source back onto a detector aboard the payload. I think it would be a good idea for source and detector to be mounted on the pivoted boom, so that they and the mirror stay in constant alignment

To balance the payload, a diametrically opposed duplicate boom will carry a similar argon probe. I would like the booms to open upwards, hopefully placing the mirrors ahead of the shock wave from the experiments in the nose cone. However, I appreciate that this may be difficult, and that you would probably prefer them to drop down.

As intimated previously, we hope that IIIB 66 (and VB 34) have E. Zipf's mass spectrometer aboard at the front of the payload, plus a forward looking 5577A photometer and nitric oxide "g" and "s" band photometers pointing sideways.

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J. Ridgeway, Esq.

- 2 -

June 23, 1972

I enclose a sketch for the layout of IIIB 66, which will also give an idea of what we need for VB 34.

If you require any more information, please let me know.

With best wishes,

Yours sincerely,

T. Broadbent

TB:VL



The Rocket also carries  
0.5577R photometer  
(12 x 3 x 3, weight 6 lbs)  
Looking forward, and 2 others  
(9 x 3 x 3, weight 4 lbs)  
Looking perpendicular to the  
axis.

Forward-looking mass  
spectrometer. Weight  
is 13 lbs.

Oxygen lamp, 6 x 3 x 3;  
Weight 4 lbs., with 2 detectors  
alongside, 6 x 2 x 2 mounted  
on the boom.

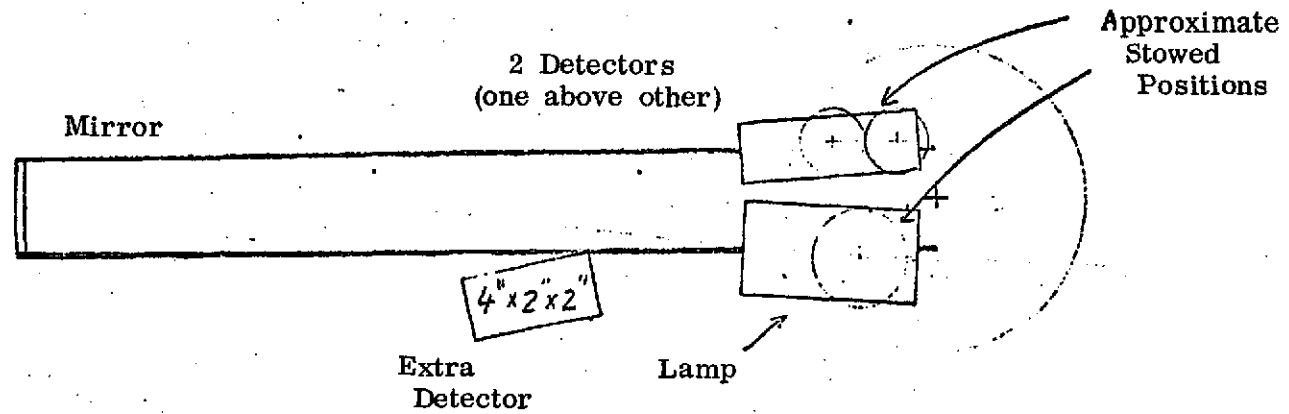
Concave Mirror

Argon lamp,  
6 x 3 x 3, weight  
4 lbs. with one  
detector along-  
side, 6 x 2 x 2.

Auxiliary off-  
axis detector  
mounted on the  
boom.

1 foot

## THE OXYGEN EXPERIMENT



## 2.3 PIONEER VENUS SCIENCE TRIP REPORT

GODDARD SPACE FLIGHT CENTER, 28 SEPTEMBER 1972

### Introduction and Summary

A visit was made to Goddard Space Flight Center on 28 September 1972 to discuss the mass spectrometer experiment with N. W. Spencer, who built the mass spectrometer for the Ames PAET experiment, was active in the Planetary Explorer program before it was transferred to Ames, and is a member of the Pioneer Venus Science Steering Group. (He is also a member of the Viking entry science team.)

#### Key points from discussion:

- First priority for a mass spectrometer measurement is the lower 10 km of the atmosphere.
- The Ames report on the PAET tests will be coming out in Icarus in a few months, but should be available from Ames before that.
- Spencer does not believe it is possible to separate the inlet system design from the mass spectrometer design.
- Spencer feels that he can do much better than the 20 lbs allotted in the SSG report, but he did not want to discuss any details of his proposed design at this time.
- The window problem for the probes is a much more difficult problem than the mass spectrometer inlet problem, in Spencer's opinion.
- Spencer sees no problems for the probe-bus mass-spectrometer, since this type of spectrometer has seen extensive development for earth satellites. It should be lined up parallel to the spin axis (along the velocity vector) to gather the maximum amount of data during entry.

Detailed Discussion

With regard to the objectives of the mass spectrometer experiment Spencer felt he couldn't improve on the orange book, which is a modification of the purple book, which reflects his inputs.

Regarding the priorities of measurements in different parts of the atmosphere, first priority lies with the lower part (i.e., the lower 10 km, rather than the upper).

Spencer feels that they are way ahead of the Ames RFP's for inlet system design which have just come out, but he did not want to discuss his approach to inlet design because of the current competition.

A report by Ames on the PAET tests will be coming out later, in a few months in Icarus. Spencer felt that a brief report he gave several years ago at Ann Arbor was probably the best reference he had on mass spectrometers. ( A copy of this report is attached.)

The new weight allotment of 20 lbs. was arrived at collectively by the SSG and he feels it is quite adequate, in fact, he thinks they can do much better than that.

Spencer declined to discuss the sampling time, because of the highly competitive nature of the business, but he felt the data rates given should be quite adequate. In his opinion, sampling time is negligible compared to any reasonable descent rate.

Ideally, one would like a continuous sample from top to surface, but some people think the mission will be successful if just one sample is obtained.

Weight, power, and volume allotments seem adequate. Power is a little less clear because it is determined so much by the inlet system requirements.

Spencer believes it is not possible at all to separate the inlet system design from the mass spectrometer design.

With regard to the mass spectrometer for the probe-bus, one wants the inlet to be parallel to the spin axis, assuming the spin axis to be along the velocity vector. It should be pointed within 10 or 15 degrees of the velocity vector. One needs all the data one can get for the probe-bus because the altitude range is not very great.

Spencer doesn't consider the UV fluorescence experiment to be a very high priority instrument. The ordering of the experiments in the probe-bus payload is more or less in order of priorities. There has been a lot of development on earth satellites for probe-bus type mass-spectrometers so he doesn't see any problems there.

Van Zahn will be proposing a mass spectrometer for the probe-bus and may collaborate with Spencer. Spencer plans to bid both.

Spencer considers that the window problem for the probes is a much more difficult problem than the inlet problem.

A preponderance of the science experiments would prefer a spinning probe.

X-620-68-350

PREPRINT

PLANETARY ATMOSPHERE MASS SPECTROMETRY

N. W. Spencer

September 1968

GODDARD SPACE FLIGHT CENTER  
Greenbelt, Maryland

For presentation at American Astronautical Society meeting, Advance Space  
Experiments, Ann Arbor, Michigan, September 1968.

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## PLANETARY ATMOSPHERE MASS SPECTROMETRY

N. W. Spencer

The present capability for Earth atmosphere composition determination by mass spectrometry makes possible in situ qualitative and quantitative measurements of the constituents of the atmospheres of the two nearest planets, Mars and Venus. Neutral particles mass ranges which are expected to extend from hydrogen to carbon dioxide in the case of Venus, and from hydrogen to krypton for Mars, are well within the capabilities of existing instruments. Available techniques allow measurements over a large pressure range, which may be as high as 125 atmospheres at the Venus surface, to the present limit of detectability, about  $10^{-9}$  torr, several hundreds of kilometers above the surfaces of both planets. Ion spectrometer systems, also providing new knowledge of the thermal ion properties of the Earth's magnetosphere, can be used in planetary atmospheres studies to resolve pressing questions regarding the nature of the ions in those atmospheres.

Advanced digital techniques now permit low data-rate systems which search the full mass range, then measure and record only those masses that exceed the in situ-determined noise level by a fixed amount. Thus the systems make very efficient use of data systems, adapting instrument operation to the composition of the atmosphere. Systems appropriate to Mars and Venus are now being prepared for flight tests. The instruments weigh about 10 pounds, require about 10 watts and are sterilizable.

### INTRODUCTION

Of fundamental importance in the study of a planet, its evolution, and the physics of its interaction with the sun's radiation, is knowledge of the planet's atmosphere. Key parameters are the constitution of the neutral particle atmosphere - that is, the composition of the gas with which the

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incident solar radiation reacts -- and the constitution of the ionized component. Also important for understanding the dominant energy transfer processes in the atmosphere are the temperatures of all the constituents -- the neutrals, the electrons, and the ions -- which may be inferred from their altitude profiles. Knowledge of these properties permits estimation of biological and evolutionary aspects of the planet, all pertinent to study of the origin of the solar system.

The present state of space exploration technology and research is sufficiently advanced to allow qualitative and quantitative measurements, in situ, of the atmospheric constituents for the two nearest planets, Mars and Venus. This has been clearly demonstrated by Venera 4, the successful Russian entry probe, which greatly advanced our knowledge of Venus. A considerably greater understanding of these planets can be gained with the more definitive atmosphere measurements that are possible with mass spectrometer systems, in contrast to the rather crude but partly effective devices employed on Venera 4. This paper describes the conceptual basis for and the details of two systems, representative of the existing instrumental technology in atmospheric composition determination, which can be applied to this problem.

Earth atmosphere studies embodying in situ measurements, which have now passed from the exploratory to the research phase, provide a background of experience on which we can draw in exploring planetary atmospheres. Direct measurement of the qualitative composition of Earth's upper atmosphere is an accomplished fact; and quantitative evaluation of key constituent concentrations, for example of atomic oxygen and ozone, is beginning to be realized. Similar measurements are required in the planets' atmospheres. Other factors clearly essential to planetary exploration are launch vehicle capability, communication data rate, and matters of systems and subsystems reliability; and all have been demonstrated to be attainable. An example is a particularly striking and



significant technological advance in the data-rate achieved for Mariner '69, to be launched in February 1969 to Mars, as compared to that of Mariner IV; 16 kilobits per second are realizable today in contrast to 8 bits per second 4 years ago.

#### Present Knowledge of the Venus Atmosphere as it Applies to Spectrometer Design

Information from the U.S.S.R. Venera 4, the U.S. Mariner 5, Earth based radar, microwave radiometry, and IR observations permits a new level of confidence in our concept of the Venus atmosphere.<sup>1,2</sup> A year ago, before Venera 4 and Mariner 5, estimates of the surface pressure ranged from a few to a few hundred Earth atmospheres, and the composition was considered on the basis of Earth based observations to be dominated by CO<sub>2</sub>. Venera 4, apparently the first successful entry probe, was at first thought to have reached the planet's surface. It indicated the surface pressure to be about 18 atmospheres, the corresponding temperature to be 550°K, and the composition to be more than 90% CO<sub>2</sub>. Mariner 5 however, though mainly confirming these results, raised a question through analysis of its trajectory that the altitudes assigned to the Venera 4 data were not correct and thus that the spacecraft did not transmit all the way to the planet's surface. At this writing, new analyses of Earth based radar-determined radii of Venus seem to confirm this belief. Thus there remains little doubt that the surface pressure is considerably higher than the last value measured by Venera 4, and it may be as high as 120 atmospheres. The corresponding temperature at the surface, based on the measured lapse rate, would be about 750°K, in reasonably good agreement with the early microwave indications. No additional data relative to the lower atmosphere composition were obtained by Mariner 5; thus the Venera 4 results confirming the presence of CO<sub>2</sub> are still the most recent and also are generally accepted. These results are summarized

and discussed in a recent paper by Jastrow<sup>3</sup> and will not be further considered here, except as summarized in Table 1.

Regarding potential planetary atmosphere mass spectrometry, however, one may now choose, with reasonable confidence, realistic system design parameters.  $\text{CO}_2$  is taken as the overwhelmingly predominant component of the lower atmosphere,\* and also as the most massive except for possible volatiles associated with cloud material, which could represent significant minor constituents. It was claimed that Venera 4 also indicated measurable concentrations of water vapor and oxygen, and nitrogen although the latter was not "measured." One can only accept the data regarding gases other than  $\text{CO}_2$  with skepticism, and thus mass spectrometers for use in the lower atmosphere of Venus must be designed to measure  $\text{CO}_2$  and other possible gases. The upper mass limit can be taken as  $\text{CO}_2$  for the "nominal" atmosphere, but can conceivably extend to masses of 200-300 amu, depending upon estimates of cloud material. For example, mercuric chloride (278 amu) has been suggested as a cloud constituent.

With respect to the upper atmosphere, Venera 4 and Mariner 5 indicated measurable quantities of only  $\text{CO}_2$  and hydrogen; oxygen was not detected. This was surprising because of the anticipated dissociation of  $\text{CO}_2$  which would produce significant quantities of CO and O. For this reason, mass spectrometer systems intended for Venus (and the Martian upper atmosphere where the same result may be obtained), should be arranged to indicate the presence of all masses from 1 amu (H) to at least 44 amu ( $\text{CO}_2$ ), to support or contradict these results.

Thus, in summary, the following design parameters for mass spectrometer systems for use in the Venusian atmosphere are selected:

---

\* It should be noted that the detection of gases in a predominantly  $\text{CO}_2$  atmosphere poses difficult but solvable problems which result from the dissociation of the  $\text{CO}_2$ .

Table 1  
VENUS ATMOSPHERE PARAMETERS FOR MASS  
SPECTROMETER DESIGN PURPOSES

Lower Atmosphere

Surface to 100 km ( $10^{-1}$  torr)

Pressure Range:	120 atmospheres	– $10^{-1}$ torr
Temperature Range:	750°K	– 200°K
Mass Range:	H <sub>2</sub>	– CO <sub>2</sub> (2-44 amu)

Upper Atmosphere

100 km ( $10^{-1}$  torr) to exosphere

Pressure Range:	$10^{-1}$	– $10^{-9}$ torr* partial pressure
Temperature Range:	250°K	– 1000°K
Mass Range:	H	– CO <sub>2</sub> (1-44 amu)

\*Estimated limit of detectability

Present Knowledge of the Mars Atmosphere as it Applies  
to Spectrometer Design

There have been many estimates of the Martian surface pressure during the past few years ranging from a few millibars to a few hundred. However, recent spectrographic determinations<sup>4</sup>, and the Mariner 4 occultation experiment<sup>5</sup> indicated the surface pressure to be about 10 mb, a value accepted until additional measurements can be made. In this case, the dynamic range demands for measuring composition are substantially less severe than in the case of Venus. CO<sub>2</sub> is the dominant lower atmosphere constituent as shown on several occasions by spectrographic observations, and by Mariner 4 data. There are gross uncertainties regarding other constituents, none of whose presence has been confirmed. It is generally assumed that N<sub>2</sub> makes up most of the balance of the lower

atmosphere, if it is not nearly all  $\text{CO}_2$ . Planetary evolution processes suggest that several other gases such as  $\text{H}_2\text{O}$ ,  $\text{CH}_4$ ,  $\text{Ar}$ ,  $\text{Ne}$  and  $\text{Kr}$  may also be present. There is a suggestion also that higher order hydrocarbons are present, although again not qualitatively confirmed.<sup>6</sup> Possible contributions from cloud material corresponding to mass numbers above 90 are not considered here.

Thus, in summary, the following design parameters for mass spectrometers for use in the Martian atmosphere are selected as shown in Table 2.

Table 2  
MARS ATMOSPHERE PARAMETERS FOR MASS  
SPECTROMETER DESIGN PURPOSES

Lower Atmosphere

Surface to 40 km ( $10^{-1}$  torr)

Pressure Range:	25 mb - $10^{-1}$ torr
Temperature Range:	$300^\circ\text{K}$ - $150^\circ\text{K} (?)$
Mass Range:	$\text{H}_2$ - Kr (2-90 amu)

Upper Atmosphere

40 km ( $10^{-1}$  torr) to exosphere

Pressure Range:	$10^{-1}$ torr - $10^{-9}$ torr*
Temperature Range:	$150^\circ\text{K} (?)$ - $1000^\circ\text{K}$
Mass Range:	H - $\text{CO}_2$ (1-44 amu)

\*Estimated limit of detectability

Pressure Range Considerations in the Use of Mass Spectrometers

All mass spectrometers identify particular gases by a sorting process that depends upon the charge-to-mass ratio of the gaseous ions. Since the gases are handled on a particle basis, the density of the ions being

sorted must always be sufficiently low to avoid significant interaction among ions or between ions and neutral particles. Thus, the analyzer section of the spectrometer is always maintained at a low pressure, regardless of the density of the atmosphere being sampled. For regions of the atmosphere where the pressure is about a  $10^{-3}$  torr or less, no pressure reducing elements are necessary. For higher densities however, various techniques can be used to provide the necessary reduction.

The following summary indicates typical pressure requirement and techniques that can be used to achieve the required density reduction:

- (a)  $10^{-4}$  torr to limit of sensitivity: corresponds to the thermosphere and higher regions of a planetary atmosphere where no reduction is required.
- (b)  $10^{-1}$  torr to  $10^{-4}$  torr: corresponds to the Martian atmosphere from about 40 to 100 km. Ionizing sources can operate throughout this range, but pressure reduction in the form of a very small orifice or slit between the source and the analyzer is required. Analyzer pumping is required for long-time operation.
- (c) 10 atmospheres to  $10^{-1}$  torr: this range includes the lower atmosphere of Mars and possibly that of Venus from altitudes of tens of kilometers upward. A "leak" in the form of sintered stainless steel or a small (microns size) hole in a diaphragm can effect the necessary reduction between the atmosphere sampling port and the ion source.
- (d) High pressure ( $\sim 100$  atm) to 10 atm: corresponds possibly to the lower atmosphere of Venus. Conventional pressure reducing valves can be used, in conjunction with the "leaks" noted above.

#### Possible Missions for Ion and Neutral Spectrometers

The need to know the ion constituents is, at least for the present, confined primarily to the upper atmospheres of the planets. Ion spectrometers at

present in use in Earth atmosphere studies can answer the more pressing questions about the planetary ionospheres. They are applicable for measurements in orbiters and probes or on any vehicle which penetrates the charged particle (thermal energies) regions about the planets.

Because of the greater sensitivity of ion spectrometers (neutral particle instruments must ionize the particles before detection and are thus generally less sensitive by about a factor of at least 100), ion spectrometers are useful for measuring much lower particle densities. Typical sensitivities for ion spectrometers without multipliers can be as high as 1 - 10 ions per cc, a value which can be increased by electron multipliers. Enhancement of the sensitivity is possible also by use of negative "drawing-in" electrodes around the spectrometer inlet.

Neutral particle instruments, although less sensitive, are also available and suitable now for in situ measurements, and can be adapted to orbiters, probes and landers. Instruments appropriate to atmosphere measurements on Earth or planetary spacecraft can uniquely identify the presence of major constituents and minor constituents in concentrations as low as 1 part in  $10^5$  or  $10^6$ . Typical sensitivities of developed systems without multipliers are about  $10^{-5}$  ampere per torr; this corresponds to a detectability limit of about  $10^7$  particles per cc which, a suitable electron multiplier may increase to possibly  $10^2$  particles per cc. This sensitivity is adequate for measurements at altitudes of several hundreds of kilometers above Mars or Venus. Because the neutral atmospheres of these planets are probably in diffusive equilibrium, measurement of the neutral particle concentrations over an altitude range of tens to hundreds of kilometers can provide a description of the nature of the planet's entire thermosphere-exosphere.

Thus, both ion and neutral concentrations can be determined in the upper atmospheres of both Mars and Venus from altitudes of about 100 km to at

least several hundred kilometers, by mass spectrometric techniques. Orbiters (and of course fly-by's) at suitably greater altitudes, and atmosphere-entry probes provide satisfactory platforms; here, however, many technological requirements must be considered, including instrument pointing direction, velocity, data rate, etc., all strongly influencing the measurement systems' design.

For the lower atmosphere (defined as the region below altitudes where the local particle mean-free-path exceeds the particle-sensitive major dimensions of the measuring instrument by perhaps a factor of 10 - 100), mass spectrometers offer equally useful and probably unique capabilities. Additional features are required to insure that the gas particle density in the ion source has been reduced to a suitably low value, by some means such as a "leak." As noted above, a "leak" can take the form of a very small (micron size) hole in a diaphragm, or a filter arrangement using sintered stainless steel; both of these have been developed.

#### Present Spectrometer System Characteristics

Although there have been spectacular advances in all regards in the capabilities of space vehicles launched to the planets, the present designs still pose demanding and challenging problems for the mass spectrometrists and the electronic system designer. Weight, power, data transmission, reliability, and the wide dynamic range necessary in an uncertain environment set compelling and challenging limits. Sterilization requirements are still imposed by firm international agreement to avoid possible contamination of a planet by organisms of Earthly origin. However, this is less problematical now than a few years ago, because of reduced requirements and improved components. Also, the advent of solid state microcircuits and new concepts for timing, voltage, and control circuits philosophy, all hand-in-hand with the growth of digital techniques, have made possible new system approaches in which we can have high confidence.

A number of years of spectrometer system development effort at Goddard Space Flight Center and the Jet Propulsion Laboratory, and other laboratories have accompanied these advances. These efforts have led to potentially very useful instruments whose general characteristics can be summarized as follows:

### Weight

Because launch vehicle and spacecraft capability for planetary missions have advanced rapidly, extensive effort has not been expended to reduce spectrometer system weight. Nevertheless, the weight for a planetary mass spectrometer system, including the spectrometer tube and associated electronics, has been reduced to about 10 pounds. This does not include, for example, the weight of devices required to reduce the gas density at the Venus surface to a value acceptable for mass spectrometry. The addition of that capability may add an additional 2 pounds to the system weight. Mars instruments would not require pressure reducers.

### Power

Spectrometer systems generally require about 10 watts when operating. In the case of neutral particle systems using hot-filament electron sources, about half of this can be attributed to filament heating. Smaller, less power-consuming filaments (0.001 inch in diameter, using about 4 watts including regulator) are reducing this power requirement. Logic and control power are not decreasing greatly because of increases in logic and control complexity that parallel the growth of system sophistication.

### Data Rate Requirement

Substantial reductions in the data rate needed to transmit useful composition data have come about relatively recently. This major advance, taken with the equally substantial increase in spacecraft communication system data rate noted above, has largely solved a most pressing problem



that once precluded adequate quantitative measurements of atmosphere composition. These advances have been made possible by the remarkable improvements in electronic data handling and logic systems, coupled with the vastly reduced power requirements of those systems. The stability now achievable in frequency and voltage levels, and the great flexibility and simplicity made possible by digital advances too, have provided systems unattainable a number of years ago.

In data rate terms, systems which scan and transmit the mass spectrum and so require a continuous and substantial data rate can, while clearly making possible the largest dynamic range, be sacrificed in favor of low data-rate techniques. These low data rate systems are arranged to search for measurable mass peaks, evaluate the peak maxima and then form appropriate digital words for transmission when called for. The former approach demands, usually, a rate of thousands of bits per second, while the latter now requires only a few hundred bits per second. This significant advance is being enhanced daily as a direct result of continuing advances in digital electronics.

#### Dynamic Range

A less dramatic yet substantial improvement has been realized in sensitivity and the signal-to-noise ratio in spectrometer systems. This leads to greater dynamic range, and compensates for the inherent loss in sensitivity experienced in using peak-reading systems as discussed above.

These gains have been possible largely as a result of advances in digital current measurement and data handling systems; with the addition of electron multipliers and pulse counters, such systems now permit detection of a very small number of individual ions, thus extending the low pressure limit. The development of high pressure ionizing sources and leaks has extended the high pressure limit. Present systems thus have adequate dynamic range to permit (a) measurements from the surface of Mars

and/or, with pressure reducers, Venus, to altitudes well into the thermosphere where diffusive equilibrium is assumed to hold; and (b) detection of possibly significant minor constituents.

#### Example of Mass Spectrometer Systems: Neutral Particle System

The spectrometer system under development at Goddard Space Flight Center\* for quantitative analysis of the Mars and Venus atmospheres employs a quadrupole electrostatic analyzer. Four parallel rod-electrodes, usually circular in cross-section, but having a hyperbolic surface (in this case) for improved resolution, (Fig. 1) comprise an ion-filter when appropriate rf and dc voltages are applied. That is, the electrostatic field established causes the electrode arrangement to pass essentially all ions of a particular  $e/m$  ratio, while inhibiting the passage of and providing a sink for ions of other charge-to-mass ratios. Adjustment of these voltages permits selection of the particular ion mass to be measured. The literature provides a number of referenced articles which discuss the properties of quadrupole mass filters.<sup>7</sup>

The addition of an ion-source, in this case employing an electron beam to ionize the gas sample neutral particles – and an electron multiplier, complete the sensor system as shown in block diagram form in the upper left corner of Fig. 2. Fig. 3 illustrates the electrode arrangement of the ion source which permits measurement of high densities – in this case corresponding to a pressure of  $10^{-1}$  torr, several orders of magnitude higher than conventional sources. Its output current/source pressure characteristic is shown in Fig. 4. Small dimensions, and particularly a very small ion exit aperture ( $0.004 \times 0.005$  inches) between the source and the analyzer, a small ( $0.002 \times 0.002$  inches) electron entrance aperture, and relatively high electrode voltages, make this improvement possible.

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\*System developed by members of Aeronomy Branch, and Experiment Engineering Branch, Laboratory for Atmospheric and Biological Sciences.

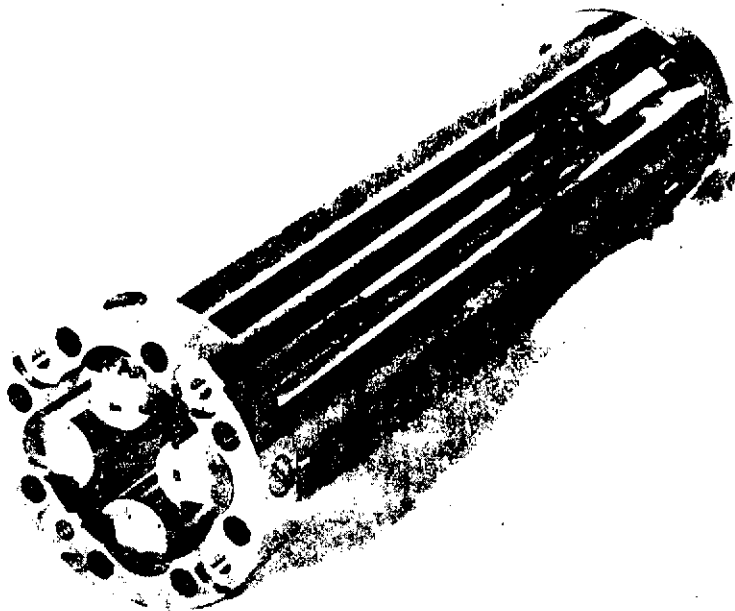


Fig. 1 Photograph of the analyzer section of a planetary quadrupole mass spectrometer instrument. The inner surfaces of the 4 rod-electrodes have hyperbolic surfaces to enhance the resolving power of the instrument.

Quadrupole spectrometer systems used in Earth atmosphere studies vary rf and dc power sources so that the useful mass range of the instrument (20-50 amu) can be scanned in time. A multirange linear electrometer, or a log amplifier, together with a pulse-counting device\*, or a combination of these, convert the electron multiplier output current to a voltage suitable for telemetry. The electrometer output constitutes the telemetry signal; during a mass range scan it contains signal, noise or both, requiring in any case a continuous channel, often with a high data rate.

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\*(counts as pulses groups of electrons produced at the output of an electron multiplier as a result of an individual ion arriving at the entrance dynode of the multiplier.)

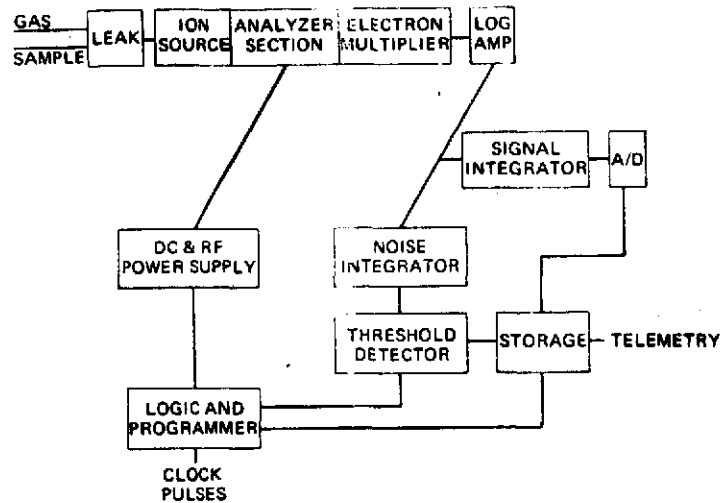


Fig. 2 Block diagram illustration of the Goddard Space Flight Center planetary quadrupole mass spectrometer system. The system employs a crystal-controlled digital rf oscillator system and an adaptive-scan logic and control system.

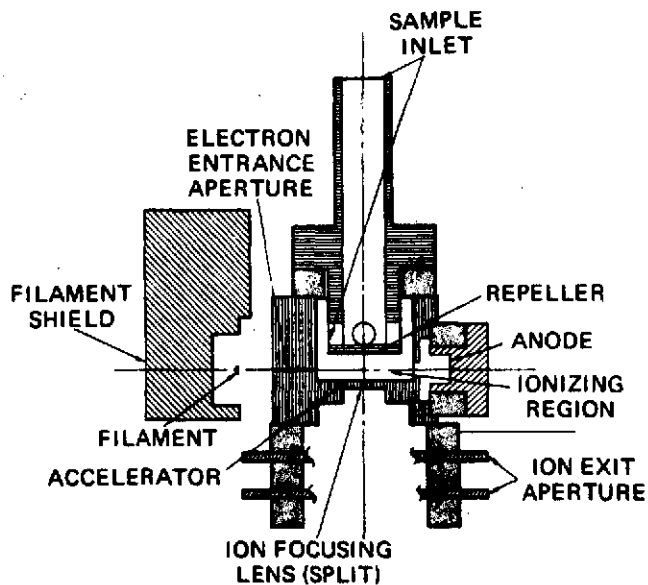


Fig. 3 Drawing of a "high pressure" ion source useful for ionizing gases with pressures as high as  $10^{-1}$  torr.

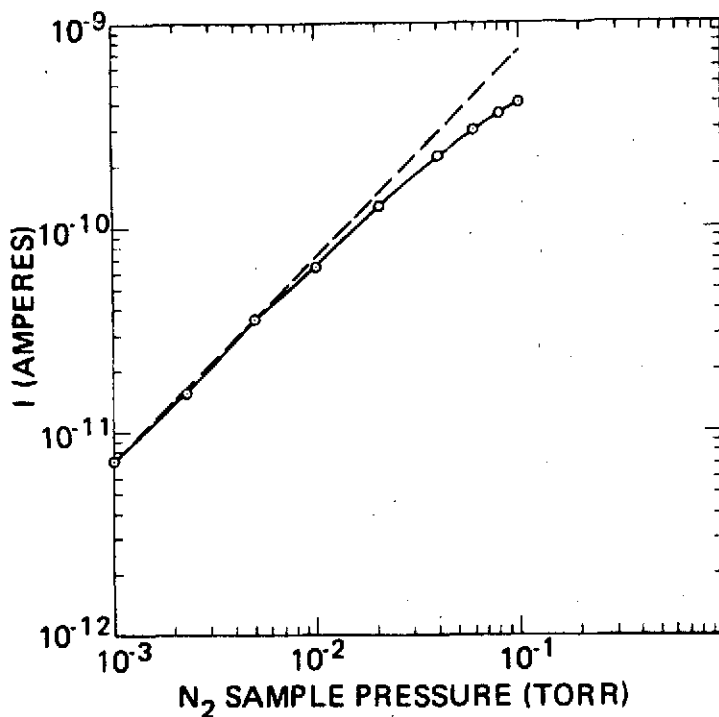


Fig. 4 Sample pressure/ion current characteristic of "high pressure" ion source.

Recent advances now permit systems with much lower data rates, whose performance in terms of minimum detectable signal closely approximates that of the more conventional systems. These advances seem to make it clearly preferable to use non-magnetic mass spectrometer systems, such as the quadrupole, in which mass separation is effected by electric rather than magnetic fields. In effect, one can trade the difficulty of mechanical and magnetic design, and attaining magnetic field stability for circuit complexity, which can be more readily and satisfactorily dealt with. In other words, the rapidly advancing electronics technology is accelerating the learning curve for spectrometer systems using electrostatic analyzer arrangements such as the quadrupole; in contrast, leveling appears to be the trend in magnetic systems.

The quadrupole system discussed here, which reflects these concepts, has been developed to optimize data systems capability. It employs the adaptive

scan approach, that is, it searches for a mass of sufficient concentration to provide a useful measurable output signal and then measures and stores the magnitude of the output signal using only a single digital word. It also records the identity of the mass of the gas measured. During a scan of the mass range however, the system automatically "by-passes" masses that are indistinguishable from noise to use the data channel most efficiently. Thus the system measures and records only those signals (gases) which have a preselected and useful S/N ratio.

Figure 2 illustrates the overall system in block diagram form. The power supply provides both dc and ac voltages generated by a multiple-crystal-controlled oscillator. These, under control of the logic, establish a series of discrete, sequential rod voltages for each integral mass from 1-90 amu. The cycle starts at a mass number known to correspond to a gas not present in the atmosphere sample, for example, amu 10. This permits evaluation of the threshold or noise level of the system, by the noise integrator. Although both the noise and signal integrator detect the noise output of the log electrometer, the noise integrator provides, in 3 milliseconds an integrated level to the logic, which is multiplied by 20, stored and used as a reference for comparison with the output of the signal integrator. If the signal integrator output does not contain a sufficient signal component to exceed the noise integrator output, the logic steps the rod voltages for the next mass number, and resets the signal integrator, permitting the procedure to be repeated. When the system steps to a mass number where the signal integrator output is significant, i.e., exceeds by 20X the noise integrator output, the electrometer output is integrated for 30 ms, converted to digital form by the A/D converter and stored, this provides in the memory, a measure of the detected gas for transmission to Earth.

This process is repeated for every mass number, but only those producing significant outputs as compared with the integrated noise level reference

are converted to digital form and stored for telemetering. Thus, the system searches sequentially through all masses at a rapid rate, slowing the scan rate only to measure those exceeding a preselected level which is referenced to the system noise level. The integrated noise level is updated several times during each mass range cycle, insuring that the reference optimally reflects the threshold S/N ratio independently of electrometer and electron multiplier drifts; such drifts cannot adequately be anticipated, but usually occur.

A system of this nature, in which a single data word suffices for quantitative measurement of a mass peak, is feasible only because of the readily attainable 100% transmission, or flat-topped peak, and stable characteristic of the quadrupole. Thus one can "program" discreet rod voltages, mass by mass in any desired order, or the system can be 'tuned' to a particular mass, confident that maximum ion transmission will be realized and that output signals proportional to the sample gas density will be measured. The data rate required by this system is a function of the number of masses existing in the sampled atmosphere, and the spectrum location identification. The time required to scan the predetermined total mass range is thus determined by the number of gases present in the atmosphere being measured, and varies in length accordingly.

#### Ion Mass Spectrometer System

For the quantitative detection and measurement of the positive-ion constitution of planetary atmospheres, a system using a Bennett ion spectrometer sensor has been derived from systems in use in Earth satellites\*, such as the OGO and the Atmosphere Explorer series. The planetary design, like the neutral spectrometer discussed above also employs a data system optimization scheme. In this case, however, flat-topped peaks

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\*Developed by members of the Aeronomy Branch, Laboratory for Atmospheric and Biological Sciences.

are not possible and thus the output signal maximum is measured by a "peak-detecting" device.

Fig. 5 is a block diagram of the system and Fig. 6 is a photograph of the rf spectrometer tube employed. The tube is simple in concept, using a series of insulated parallel grids carefully spaced and held in place by a (brazed) ceramic structure. It has a very large entrance aperture as compared with most spectrometers which affords high sensitivity in spite of the relatively low ion-transmission efficiency (5-10%). The mass selection capability of the tube derives from the coincidence of the drift time of ions of a particular mass between groups of grid triplets and the period of a suitable rf voltage applied to the grids as described in the references. No ion source is required, as the purpose is to detect and measure ambient atmospheric ions. An electron multiplier is not usually employed, for conventional electrometer systems lead to overall system sensitivities, in atmospheric terms, of the order of 1-10 ions per cc. The ions of a particular charge-to-mass ratio reaching the collector of the sensor comprise a current which is measured by several linear electrometers of sensitivities differing by a factor of 10 which together provide a dynamic range of 3-5 orders of magnitude as required.

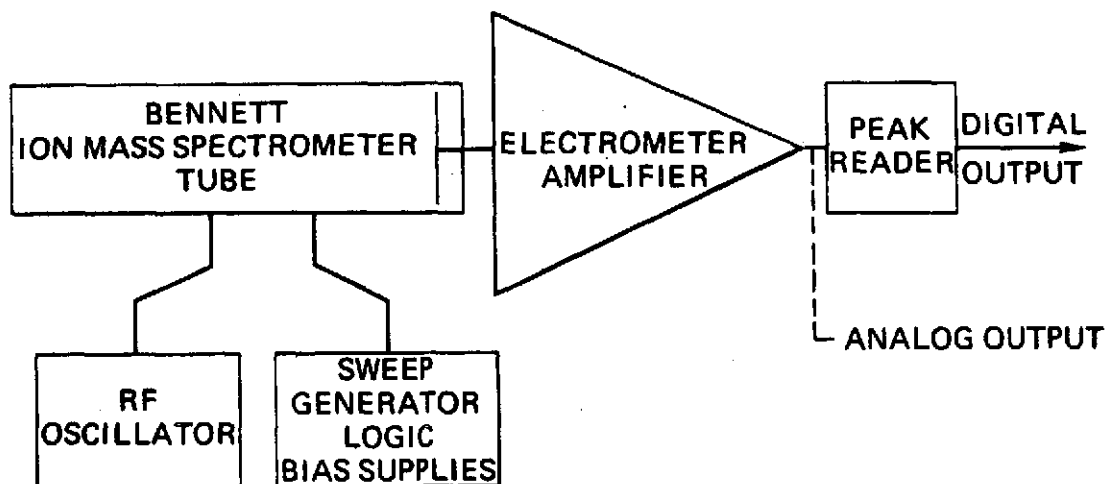


Fig. 5 Block diagram illustration of positive-ion mass spectrometer system.



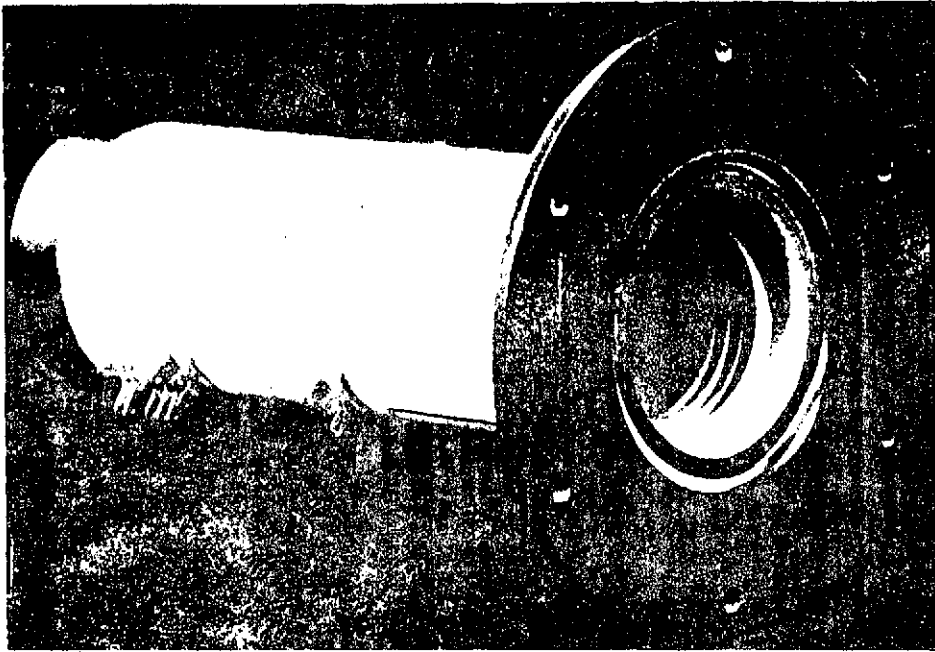


Fig. 6 Photograph of Bennett ceramic ion spectrometer sensor showing grid assemblies.

The peak-detecting system searches among the electrometer outputs and selects that which is on-scale. It then periodically (1000 times/second) converts the output signal to digital form, and compares this value to a previous digitized value. If the most recently digitized value exceeds the reference value, the value is replaced in the interim-storage register. This procedure continues, (while the system is mass-number scanning) the magnitude of the value in interim-storage continuously being replaced, provided the newly digitized value exceeds the stored value by 3 db. When the maximum of the ion current peak has been attained (a subsequent value reflecting a decrease of 3 db) the value in the interim-storage is transferred to regular storage, where it remains until called for by the logic/telemetry system of the spacecraft.

Fig. 7, a photograph of a telemetry record of a test flight of this system, illustrates the technique. The lower three traces are the outputs of 3 electrometers whose sensitivities differ by factors of 10 as noted. The

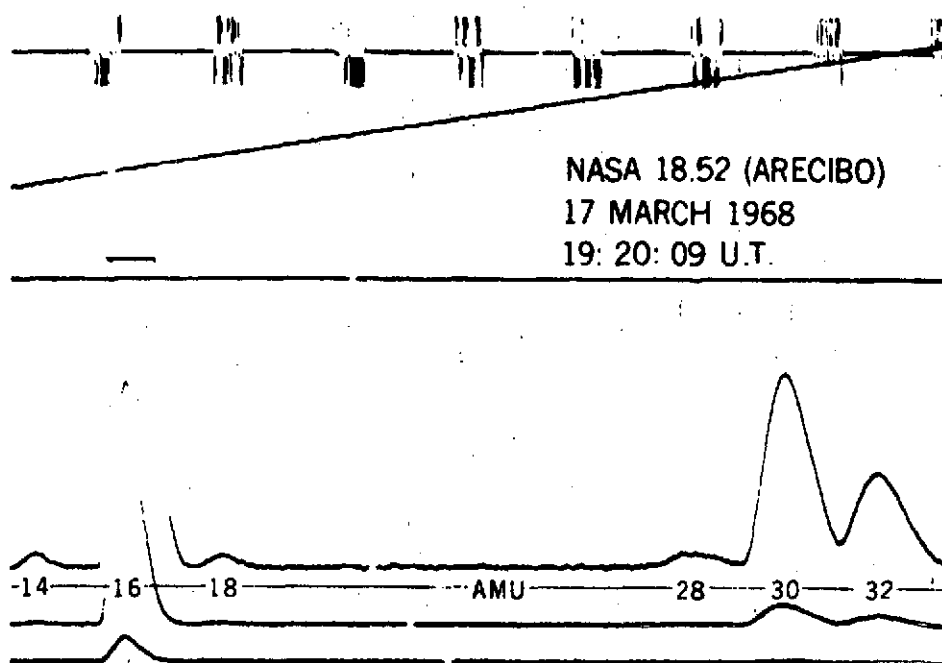


Fig. 7 Photograph of a portion of a telemetry record from an Earth atmosphere flight. The lower 3 traces represent the outputs of 3 electrometers with sensitivities differing by factors of ten. The upper trace conveys, in analog form, digital representations of peak heights and mass identification.

next trace is a reference level, and the next represents the linear sweep rate of the system. The top trace contains the digital output, corresponding to mass peak magnitude and identification, provided by the peak detecting system.

Fig. 8 shows oxygen ion densities, measured in the Earth's upper atmosphere, during a flight test. The two sets of data points shown were obtained from both the peak reading system, and the usual technique of measuring peak deflections on the analog telemetry record. It can be seen that the results of the two techniques agree rather well. Reference to Fig. 7 demonstrates that a dramatic savings in data rate has been accomplished by the peak reading device.

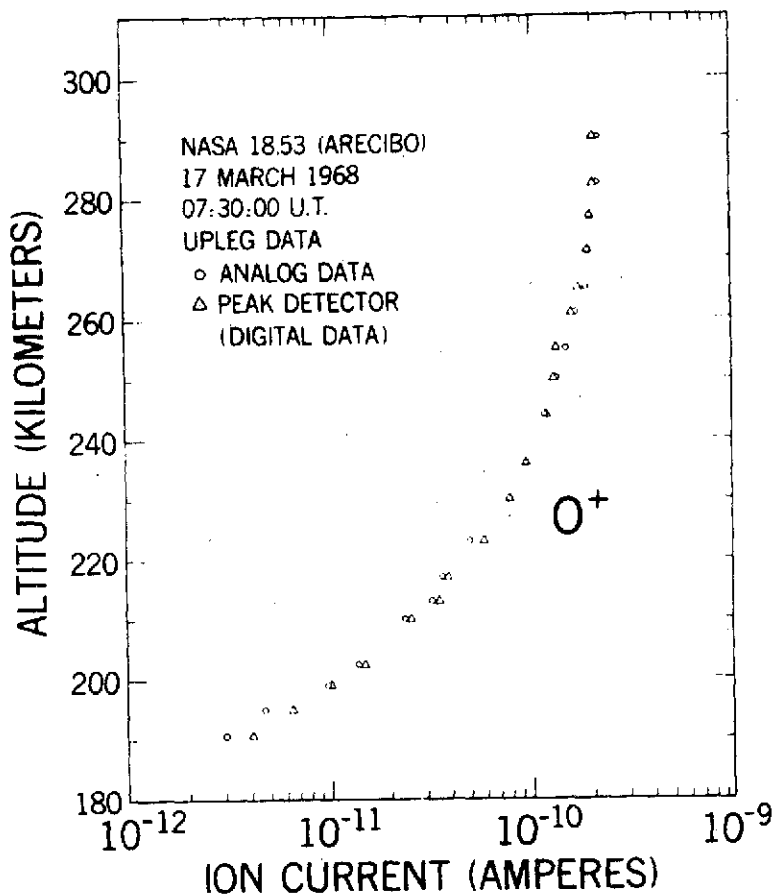


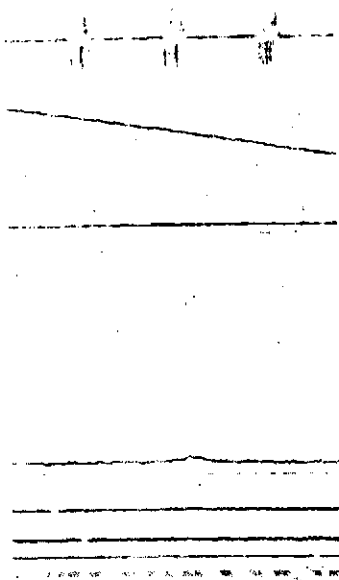
Fig. 8 Earth atmosphere atomic oxygen ion profiles obtained from a test flight. Results from both a typical analog telemetry system and a peak detecting digital system are shown for comparison.

Finally, Fig. 9, similar to Fig. 7, but showing a portion of the flight where the signal-to-noise level was much less, illustrates the present limiting signal-to-noise ratio capability of the system. This example corresponds to a sensitivity of about 10 ions per cc.

The overall characteristics of the system are shown in Table 3.

#### SUMMARY

Mass spectrometer systems suited to in-situ measurements of both neutral and charged particles are available and offer a unique capability for study of planetary atmospheres. Although two specific types intended for Mars



NASA 18.53 (ARECIBO)  
17 MARCH 1968  
07:30:00 U.T.

FLIGHT TELEMETRY RECORD  
SHOWING ANALOG PEAK  
AND CORRESPONDING DIGITAL  
READOUT OF O<sup>+</sup> ION CURRENT  
NEAR THE LIMITING SENSITIVITY  
OF THE INSTRUMENT

Fig. 9 Photograph of a portion of an ion spectrometer test flight telemetry record illustrating a near-limiting sensitivity case. The digital peak detecting system operates satisfactorily at this signal-to-noise level, which is also easily detectable in analog form.

Table 3  
SUMMARY CHART OF POSITIVE-ION MASS  
SPECTROMETER CHARACTERISTICS

DYNAMIC RANGE (1-45 AMU)	ION CURRENT: $1 \times 10^{-14}$ TO $5 \times 10^{-9}$ AMPERES ION CONCENTRATION: 1 TO $1 \times 10^5$ IONS/CM <sup>3</sup>
WEIGHT	8 POUNDS $\pm 10\%$
SIZE	6 IN. $\times$ 6 IN. $\times$ 10 IN.
POWER PROFILE	4 WATTS, $\pm 10\%$ , FULL ON IN ALL MODES
DATA RATE	10 BITS PER SECOND
COMMANDS	NONE
TEMPERATURE ENVIRONMENT	FUNCTIONAL: 0° TO 50°C STORAGE: -10° TO 60°C
SPATIAL RESOLUTION (ALONG ORBIT)	50-100 KILOMETERS

and Venus use, have been chosen for development at Goddard Space Flight Center, and are discussed in this paper, it should be recognized that there are many other possibilities. Magnetic deflection instruments, both single and double focussing, and monopoles can be employed for both ion and neutral measurements. Quadrupoles can also be used for ion measurements as well as neutral particles.

Continued development of both quadrupole and magnetic systems is desirable, and should be encouraged, to improve the already substantial usefulness of the existing instruments.

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7. See for example, W. Paul, H. P. Reinhard, and U. Von Zahn, Z. Physik, 152, 143 (1958).

8. Johnson, C. Y., "Bennett Radio Frequency Spectrometer, Encyclopedia of Spectroscopy," edited by G. L. Clark, Reinhold Publishing Corp., New York, 587-598, 1960.
9. Taylor, H. A., Jr., L. H. Brace, H. C. Brinton, and C. R. Smith, "Direct Measurements of Helium and Hydrogen Ion Concentration and Total Ion Density to an Altitude of 940 Kilometers," J. Geophys. Res., 68, 5339-5347, 1963.

## 2.4 PIONEER VENUS SCIENCE TRIP REPORT

MIT, 29 SEPTEMBER 1972

### Introduction and Summary

As part of a visit to MIT on 29 September 1972, a discussion was held with Dr. John S. Lewis of the Department of Earth and Planetary Sciences on the atmosphere of Venus. (A separate trip report is being issued on discussions with Dr. I. I. Shapiro on DLBI techniques.)

Key points from the discussion:

- Lewis has been a science consultant to AVCO for 2 1/2 years in a similar capacity to that which McElroy will have with Hughes, but this is now terminated and Lewis is available for consulting work.
  - Lewis is co-proposing with Spencer for the mass-spectrometer experiment and is also proposing on a "long shot" plasma chromatograph instrument with Bendix.
  - In an SSG presentation to Fletcher on 17 October, Lewis will be giving the pitch on why study Venus.
  - Lewis believes that 4 or 5 widely spaced samplings through the atmosphere are all one needs to meet the science objectives.
  - Lewis believes that the essential measurements to make are accurate mass spectrometer measurements in the lower atmosphere, and a nephelometer trace through the atmosphere to tell where clouds are.
  - With regard to atmospheric turbulence to be expected, he suggests waiting to see if the Russians publish anything from Venera 8.
- A meeting is scheduled in Moscow in about a month to release

Venera 8 data.

A-89

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Detailed Discussion

Lewis is presently under contract to AVCO but this is being cancelled since AVCO is withdrawing from space work. He is also under contract to Dynatron but not related to Venus. He was approached a couple of times by Martin Marietta, but not during the last week when he has been free from AVCO. Thus he saw no conflict of interest in talking to us. For AVCO he took a science-overlook view, in a close symbolic relationship in which he was present at all design reviews. (Similar to the role McElroy will be playing for us.) He was a consultant with AVCO for 2 1/2 years.

Lewis is a co-proposer with Spencer for the mass-spectrometer experiment, and he also plans to propose on a long-shot plasma chromatograph with Bendix, as a back-up to the mass spectrometer.

There is an SSG presentation to Fletcher scheduled for 17 October, and Lewis will be giving the pitch on why study Venus.

One thing that excites him about the Venus atmosphere is that it can tell a great deal about the surface of the planet and its evolutionary history.

Cloud structure is a back-door way of getting the same kind of data. Conversely a mass-spectrometer measurement in the lower atmosphere tells what the clouds should be.

Volcanic sublimates should come out of the surface and stay in the atmosphere permanently.

Models for the cloud structure are in a pretty sorry state because there are so few measurements.

It is a virtual certainty that the upper cloud tops are concentrated HCL acid. Another major cloud layer is probably made up of volcanic sublimates, e.g., arsenic, antimony, mercury, bromine, sulfur. There are so many possibilities that one can't guess.

There is no agreement on components of the main cloud deck below the cloud tops. The Russians claim they have now detected ammonia in the atmosphere. Lewis is deeply suspicious of Russian chemists, but can't rule out the possibility of ammonia occurring in such compounds as ammonium bromide or ammonium chloride.

A good detailed mass-spectrometer observation at the lower altitudes would be extremely valuable. About 4 or 5 widely spaced samplings through the atmosphere are all you need; there is no need for continuous observations through the cloud layer.

What one needs is accurate mass-spectrometer measurements in the lower atmosphere and a nephelometer trace through the atmosphere to tell where the clouds are.

The Russians haven't released their solar photometer data from Venera 8. Extinction probably occurred at a temperature of 240 to 270°A. (The Time Magazine report that 2/3 of the light reaches the surface is complete hogwash.) If more than 1% of the solar flux reaches the surface Lewis would be surprised. But he believes some flux does reach the surface.

With regard to the turbulence to be expected, which swings the attenuation model, Lewis suggests waiting to see if the Russians publish anything from Venera 8; he can't give any quantitative numbers. There will be a meeting in Moscow in about a month, with some Westerners invited, in which they will probably give all the data on Venera 8 that they intend to release. Fletcher will get a hard-sell that the Soviet experiments that did work didn't return much useful data.

Regarding re-entry cooling, Lewis has the strong feeling that it is easier to design the main probe to reach the surface than to survive. Putting a large number of surface experiments on a first flight would jack up the cost, and the program might not go. The first mission is atmosphere oriented.

Lewis gave us copies of four papers on the Venus atmosphere:

"Geochemistry of the Volatile Elements on Venus," Icarus 11, 367-385 (1969);  
"Refractive Index of Aqueous HCL Solutions and the Composition of the Venus  
Clouds," Nature, pp. 295-296, April 2, 1971; "The Atmosphere, Clouds, and  
Surface of Venus," American Scientist, September-October 1971, pp. 557-566;  
and "Composition of the Venus Cloud Tops in Light of Recent Spectroscopic  
Data," The Astrophysical Journal, 15 January 1972, L75-L79. One of these,  
a general survey paper, is attached.

# The Atmosphere, Clouds, and Surface of Venus

*Some chemical, geochemical, and meteorological perspectives on Earth's twin*

Venus is Earth's twin in many respects. In mass, radius, density, and distance from the sun, Venus is far more Earth-like than the other planets in the solar system. In recent years, however, several unsettling disparities between Venus and Earth have come to light. Spurred by great advances in radio and radar astronomy, in earth-based infrared spectroscopy, and in spacecraft exploration during the past decade, our theoretical picture of Venus has changed repeatedly and unpredictably over a wide range of possibilities. Frequently it has been impossible for the workers in these fields to reach a consensus on working models for Venus's atmosphere and surface. There has frequently been a tendency toward an undisciplined proliferation of theories to explain a limited (and often conflicting) body of knowledge.

Partly as a result of the success of the Mariner II, Venera IV, V, VI, and VII, and Mariner V Venus probes, a number of theories about the planet have met their demise. Although unanimity is still lacking in numerous important questions, at least it is clear that essentially everyone is now talking about the same planet.

It is amusing but instructive to recall that, just a few years ago, when our data on Venus showed only that its atmosphere was CO<sub>2</sub>-rich and that the planet

emitted a substantial radio wavelength flux, it was argued by various parties that Venus was: (1) a moist, swampy planet teeming with life, or (2) a warm planet enveloped by a global ocean of carbonic acid, or (3) a cool, Earth-like planet, with water on its surface and a dense ionosphere, or (4) a warm planet covered by massive precipitating clouds of water droplets, producing intense lightning discharge activity, or (5) a planet with cold polar regions covered by ten-kilometer-thick icecaps, with hot equatorial regions far above the boiling point of water, or (6) a hot, dusty, dry, very windy planet covered by a global desert, or (7) an extremely hot, cloudy planet, with molten lead and zinc puddles at the equator and seas of bromine, butyric acid, and phenol at the poles. The emerging (but still very imperfect) view of Venus is genetically related to models (6) and (7), but the violent winds, the metallic puddles, and the chemical warfare in the polar regions have all fallen into disfavor.

In addition to the general acceptance of high (>600° K) surface temperatures on Venus, two other marked differences between Venus and Earth have emerged. The overwhelming weight of evidence from infrared spectroscopy is that the abundance of water vapor above the visible clouds of Venus (at a temperature of near 240°K) is less than one part in 10<sup>4</sup> of the total pressure, while searches for evidence of an H<sub>2</sub>O absorption band in the thermal radio emission from Venus fail to disclose as much as ~0.8% H<sub>2</sub>O in the lower atmosphere. It is very likely that the amount of water vapor in the atmosphere of Venus is 10<sup>-3</sup> or 10<sup>-4</sup> times the amount of water in Earth's biosphere. It is of considerable importance to determine whether Venus differs from Earth in this respect because of different conditions of origin or because of divergent planetary evolution brought about perhaps by the closer proximity of Venus to the sun.

*John S. Lewis is assistant professor of geochemistry and chemistry in the Departments of Chemistry and of Earth and Planetary Sciences at M.I.T. Since completing his doctoral studies under Harold C. Urey at the University of California, San Diego, he has been engaged in research on the composition and structure of planetary atmospheres, the thermodynamic and isotopic geochemistry of rare minerals in meteorites, models for the origins of the planets, and the origin and evolution of the atmospheres of the terrestrial planets. His teaching interests include courses on planetary atmospheres, meteorites, and planetology. He has served as a member of the National Academy of Sciences/Space Science Board's panels on the exploration of Venus and on the outer solar system. He is a member of the Science Advisory Group on the Outer Planets, which advises NASA on science objectives and implementation for the Grand Tour and related programs. Address: Department of Earth and Planetary Sciences, M.I.T., Cambridge, MA 02139.*

A-93 Active radar observations have disclosed that Venus

rotates extremely slowly on its axis and, for unknown reasons, Venus presents exactly the same side toward Earth every time it passes between Earth and the sun. Strangely, the rotation of Venus is retrograde; that is, it rotates in the direction opposite to the rotation of Earth and the orbital motions of the planets. Although ad hoc explanations of this phenomenon can be offered that explain it as the natural result of unobservable interactions with objects which unfortunately no longer exist, I feel it is safe to say that we do not understand it. How Venus could find its rotation locked on to Earth despite the fact that the sun's tidal force on Venus is some  $10^4$  times larger than Earth's is far from clear.

Given the extremely slow rotation rate, the very high surface temperature, and the extreme aridity of Earth's twin, we are confronted by the unpleasant necessity of understanding these phenomena. But the exploration of Venus for its own sake is not advocated; rather, we should study Venus *in relation* to Earth and the other planets. This infant science is called planetology.

## Earth in relation to other planets

Earth—with its atmosphere and oceans, its complex biosphere, its crust of relatively oxidized silica-rich sedimentary, igneous, and metamorphic rocks overlying a reduced interior in which metallic iron is stable, with its ice caps, deserts, forests, tundra, jungle, grasslands, fresh-water lakes, coal beds, oil deposits, volcanoes, fumaroles, factories, automobiles, plants, animals, magnetic field, ionosphere, mid-ocean ridges, convecting mantle, and large axial inclination—is a system of stunning complexity. Let us look at Earth for a moment as an outside observer would and ask the questions which would arise in his mind as he tries to understand his discoveries.

Our postulated observer would probably discover water vapor and oxygen first by standard spectroscopic means. He would have difficulty understanding the presence of a large amount of free oxygen on a planet with a metallic core. He could postulate that all the oxygen is derived from photolysis of  $H_2O$  by solar ultraviolet light and that the persistence of so much  $O_2$  in the atmosphere is evidence for the complete oxidation of all ferrous iron in the crust to ferric oxides. He would be on sound theoretical grounds, but wholly wrong. Let him improve his observational techniques somewhat, and he would find that  $CO_2$  was about ten times more abundant than equilibrium with carbonate minerals would permit. He might explain this as due to the complete conversion of all calcium silicates in the crust to calcium

carbonate, or postulate that gases escaping rapidly from the interior of the earth were responsible. Again his arguments would be plausible but wrong.

Let him detect nitrogen oxides in the atmosphere; would he anticipate the existence of lightning discharges? Would the presence of a part per million of methane lead him to postulate anaerobic decay? Would his observations of carbon monoxide lead him to suspect that it was arising in large part from Earth's oceans? Let us attempt to imagine his chagrin when he discovers that the very nitrogen in the atmosphere ought to be severely depleted by chemical equilibration with atmospheric oxygen and liquid water to produce a dilute solution of nitric acid in the oceans! Would he be successful in postulating organisms living in the ocean and protecting themselves from noxious nitric acid by destroying it enzymatically as fast as it is made? Would he attribute formaldehyde over Los Angeles to cars? Would  $SO_2$  over Hawaii suggest volcanoes? How would he explain terpenes in the air over the Great Smokies?

The unsettling truth about Earth's atmosphere is that virtually every component is produced, or destroyed, or both, by unique mechanisms. The number of different effects which must be postulated to describe the growth, decay, or regulation of the abundances of the atmospheric gases is probably greater than the number of gases present. This is true even of the rare gases, whose relative abundances and isotopic compositions are not by any means universally constant. Clearly the main difficulty in the way of understanding these processes and of gaining the least appreciation of the origin of Earth's atmosphere and of life on Earth is that of separating or isolating these many competing processes.

I am not overstating my case. Such fundamental questions as, What is the composition of volcanic gas? How does it depend on the chemistry of its parent magma? and What was the composition of the earliest atmosphere of Earth? defy our best experimental and theoretical efforts. Virtually every volcanic gas analysis ever made betrays evidence of gross contamination by air.

One of the most crucial questions is the state of oxidation of the parent magma, but so facile are oxidation reactions involving  $CO$ ,  $CH_4$ ,  $H_2S$ ,  $COS$ , etc. that the least contamination by air utterly destroys the fragile evidence. Also very common is contamination of volcanic gases by groundwater, organic matter, dissolved gases, and volatile constituents of the host rock through which the magmatic gases escape.

A major reason for my interest in Venus is that the lower atmosphere presents us with an essentially unperturbed example of chemical equilibrium between atmosphere and lithosphere. In addition, the photochemistry of the upper atmosphere of Venus holds promise of being sufficiently different from our experience on Earth to assist greatly in understanding the general photolysis-recombination process. Isolating and understanding gas-rock reactions is an absolute necessity in any attempt to understand the origin and early compositional evolution of Earth's atmosphere, since only this can give us the boundary conditions under which life must have originated. The fundamental question of the ubiquity of organic material and of life will be much more tractable than it is now after such an understanding is attained.

Further, it is probable that there is an intimate connection between the origin and growth of continental blocks and the origin and evolution of the atmosphere. There is even a possible strong connection between the origin of the core of a planet by a catastrophic differentiation process and the sudden production of a substantial atmosphere by the heat pulse from core formation. Because of the great change in the rotational moment of inertia of a homogeneous planet as it differentiates to produce a siliceous mantle and a metallic core, the rotational angular velocity of the planet may be considerably augmented, in effect, by a fundamentally geochemical occurrence.

In turn, the presence of a conductive core is essential for the existence of a large planetary magnetic field, which in turn determines whether the upper atmosphere of the planet is shielded by its magnetosphere or whether in fact the solar wind is able to "sweep" the planet's ionosphere. Because the rates of escape of hydrogen and helium are sensitive functions of the thermospheric composition and structure, secular changes in the chemistry of the atmosphere may be strongly dependent on the strength of the magnetic field (that is, on the rotation rate and the presence of a metallic core, which in turn depends on the path followed during geochemical differentiation). Current volcanic gases are frequently recycled volatiles from sedimentary ocean-floor deposits which are being forced down under the edges of continental plates by the forces driving sea-floor spreading and continental drift. All these effects working upon Earth's atmosphere can be seen to be very complexly interrelated.

Up to this point I have dealt exclusively with chemical problems of interpretation: but this is merely the one facet of Earth's atmosphere that I

wish to discuss in detail. Let me also indicate to non-chemists another respect in which Earth's atmosphere is so complex that it defies comprehension.

If we attempt to understand planetary-scale atmospheric (or oceanic) circulation in a general way, we have a number of major effects to consider. First, there is the penetration of sunlight into the atmosphere. Second, there is absorption of sunlight at surfaces with attendant reemission of infrared radiation. Third, there is absorption of this infrared radiation by the atmosphere. Fourth, there is convection of strongly heated parcels of atmosphere. Fifth, there is radiative cooling of the atmosphere on the night side of the planet and at high latitudes. Sixth, there is mass motion of the atmosphere conveying heat from the equatorial region to the poles. Seventh, there is severe distortion of flow on rotating planets due to the Coriolis effects. Eighth, there is evaporation, condensation, and transport of latent heat. Ninth, there is modification of all radiative processes by the formation of cloud cover. Tenth, there is steering of winds by topography. Eleventh, there are local meteorological effects which can, by various feedback mechanisms, alter features of the planetary circulation. Twelfth, there is the most general effect of all: that our succinct formulation of effects is invariably incomplete, inaccurate, or simply misleading.

As we attempt to study the interactions of these effects in a reasonably general way, we soon find our attention drawn to the fact that the dynamic, radiative, and Coriolis forces are all of great importance on Earth. Mars is dominated by radiative effects, Venus and Jupiter by the dynamics. But Venus and Jupiter have a difference which is of prime importance: Jupiter is a rapidly rotating planet, while Venus is virtually free of Coriolis forces. We thus are in the remarkable position of being able to learn what we need to know about Earth's meteorology most readily by conducting a simultaneous study of Venus, Mars, Jupiter, and Earth. Venus is of particular interest in that the area of Earth's surface in which the circulation is most poorly understood is the tropics; near the equator the Coriolis forces are unimportant and Hadley cell circulation is found. Venus appears to present a nearly ideal opportunity to study such circulation with minimal disturbance from other forces.

### Venus: background

In terms of the comparison between Venus and Earth which I suggested earlier, I have mentioned that the extremely high surface temperature of Venus came as a great surprise to many scientists. What is

the surface of Venus two to three times as hot as Earth? Exactly how hot is the surface of Venus, and how does the surface temperature vary with latitude and solar phase angle? Radio interferometer measurements of temperature differences on the surface of Venus imply that the coldest region on Venus may be within 10–20°K of the hottest region and that the coldest region lies on the equator near the sunrise terminator. Recent estimates of the surface temperature all fall in the range  $700 \pm 100^\circ\text{K}$ .

It is not yet known whether the familiar greenhouse effect can provide such high surface temperatures in a rigorously self-consistent model. And if an evolutionary model can be found for Venus that gives the desired results, would it predict the same catastrophe for Earth? The most crucial data for the elucidation of this problem include precise absolute temperature profiles through the atmosphere, a measurement of the penetration of sunlight into the atmosphere, and reliable temperature-difference maps of the surface. An indirect technique that places useful limits on the surface temperature and pressure is surely worth pursuing.

The present data concerning the nature of the surface and crust of the planet are quite sparse. Radar astronomers have found that the dielectric constant of the surface is typical of silicates, which comes as a surprise to hardly anyone. Furthermore, it is found that the surface of Venus is remarkably free of high vertical relief near the equator. The planet appears generally flat to  $\pm 1.5$  km elevation, and a lone feature as high as 2.5 km above the mean has been detected. There is not the least shred of evidence for continental blocks and ocean basins on Venus, quite contrary to our knowledge of Earth and Mars. Plainly an indirect way to determine the chemical and physical properties of the surface would be of great value.

Our knowledge of the atmospheric composition is largely derived from Earth-based spectroscopic observations of Venus and thus refers to the atmosphere above the main cloud layer, near the 240°K level. The atmosphere in this region is nearly pure  $\text{CO}_2$ , with about one part in  $10^4$  each of  $\text{H}_2\text{O}$  and  $\text{CO}$ . In addition there is about one part in  $10^6$  of  $\text{HCl}$  and one part in  $10^8$  of  $\text{HF}$ . The detection of  $\text{HF}$ , a parts-per-billion constituent of the atmosphere of Venus, by Earth-based infrared interferometry is surely one of the most impressive achievements of planetary astronomy. Upper limits on dozens of other gases have been set by spectroscopists, and to date only these five constituents of the troposphere have been confirmed. It is interesting that none

of the sulfur-bearing gases  $\text{H}_2\text{S}$ ,  $\text{COS}$ ,  $\text{SO}_2$ , and  $\text{SO}_3$  have been detected on Venus despite their abundance in terrestrial volcanic gases.

The clouds of Venus have been a favorite topic for controversy, and here the matter is still in a very uncertain state. Half a dozen species are currently favored by different individuals as making up the visible clouds. Among the most widely advertised are water or ice, silicate and carbonate dusts, ammonium chloride, compounds of the volatile elements mercury, arsenic, etc., carbon suboxide and its polymers, hydrochloric acid solution or solid hydrates of  $\text{HCl}$ , ferrous chloride dihydrate, etc. Each species has more detractors than supporters.

Several criteria may be used in judging the plausibility of these suggestions. First, we require compatibility with the observed atmospheric gases. Second, we require compatibility with the infrared reflection spectrum of the clouds. Third, we must match the refractive index for the cloud-top particles as derived from polarization of reflected sunlight. Fourth, the space-probe data on cloud structure should not be contradicted. Of course the question of the cloud composition and structure is intimately tied to the previously discussed question of atmospheric composition and structure. We therefore combine these problems to formulate the general question, Why does the atmosphere have its observed composition, and what are the implications for the clouds?

The upper atmosphere of Venus differs markedly from that of Earth in several important ways. The temperature of the exosphere of Venus is far lower than that of Earth's; the solar wind impinges upon the upper atmosphere of Venus but is held off at great distance from Earth by its large magnetic dipole moment; the processes governing the ionospheric structure on Venus are due almost exclusively to the photochemistry of  $\text{CO}_2$ , not  $\text{O}_2$  as on Earth. Photolysis of  $\text{HCl}$  and traces of gases such as  $\text{H}_2\text{S}$ ,  $\text{HBr}$ , and  $\text{HI}$  could dominate the photochemical production of free hydrogen. Since the rate of hydrogen loss is an important parameter in any discussion of chemical evolution of the atmosphere, and since the rate of photochemical production of free hydrogen may depend sensitively upon the abundance of trace gases such as those mentioned above, it seems that rather detailed chemical models of the atmosphere are needed before any sweeping generalizations can be made concerning the hydrogen escape rate averaged over geological time.

The topic of evolution of the atmosphere brings us

back to another point of tangency between Venus and Earth studies. Current models for the origin of the solar system suggest that modest differences between the conditions of temperature and pressure at the points in the solar nebula where Venus and Earth accreted may have resulted in profound differences in the degree of retention of volatile elements. It is quite plausible to suggest that Venus accreted at higher temperature than Earth, that it never contained as much water as Earth, and that even identical conditions of degassing of the interiors might have resulted in completely different early atmospheric composition. Because of the exponential temperature dependence of the dissociation pressures of solids containing volatiles, it is extremely difficult to assume constancy in the *relative* abundances of two volatiles in planets which may have accreted at very different temperatures.

All of these problems are difficult; none of them can at present be solved adequately. It is a recurrent misfortune that our understanding of many of these problems requires a detailed knowledge of the properties of the lower atmosphere and surface, while the great preponderance of the observational data at our disposal refers to the atmosphere above the clouds. Even the Venera IV-VI deep-entry probes left the lower 60 to 80% of the atmosphere unplumbed.

The Venera VII deep-entry probe, which reached Venus on December 15, 1970, was especially designed to withstand the high temperatures and pressures of the lower atmosphere. The scientific instrumentation of this probe was quite modest, with only four thermocouple gauges and four barometers aboard. One temperature gauge and one pressure gauge reported only very coarse measurements over a very wide range, while much more sensitive measurements over limited ranges of pressure and temperature were made by the other instruments. Unfortunately the commutator switch, which was supposed to select the outputs of instruments for transmission back to Earth, failed to function. As a result the *only* data returned by the probe were coarse temperature measurements, which were digitized in  $\sim 20^\circ$  increments. Because the velocity of fall of the probe through the atmosphere can be measured from the Doppler effect on its radio signal, it is possible to reconstruct much of the lower atmospheric structure from aerodynamic calculations on the entry probe and its parachute.

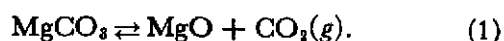
It should not be necessary to stress that even the region probed by the Venera series to date is very poorly characterized. Even the temperature and

pressure profiles currently available cannot be interpreted reliably without detailed chemical analyses of a sort not amenable to the extremely simplistic chemical analytical procedures used by the Venera probes. What is required is a detailed mass spectrometric analysis of the lower atmosphere, detailed temperature and pressure profiles, and some basic data on wind velocities and directions.

## Geochemical modeling of Venus

But given our present knowledge of the atmospheric composition and clouds of Venus, what conclusions can be made regarding the surface conditions, the state of the lower atmosphere, the variability of surface temperature, and the origin and history of the atmosphere of Venus? How can we use the available data most effectively?

The basic working hypothesis in attempting to answer these questions is that chemical equilibrium may be attained in the atmosphere-lithosphere system on Venus. This simple assumption is remarkably powerful as a means of placing limits on the surface temperature because of the exponential dependence of the abundances of gases on the factor  $-1/T$ . Basically we shall attempt to consider every reaction between possible atmospheric constituents and surface minerals which can control the abundance of the gas. To illustrate the concept consider the equilibrium



Here the equilibrium constant,  $K$ , for the reaction is given by

$$\log K_1 = \frac{-\Delta G_1^\circ}{2.303 RT} = \log P_{\text{CO}_2} \frac{a_{\text{MgO}}}{a_{\text{MgCO}_3}}. \quad (2)$$

$\Delta G_1^\circ$  is a function of  $T$  alone, while the expression on the right can often be simplified. For a system in which pure MgO and pure MgCO<sub>3</sub> are present,  $a_{\text{MgO}} = a_{\text{MgCO}_3} = 1$ , and we find

$$\log p_{\text{CO}_2} = f(T) = \frac{\Delta S^\circ}{2.303R} - \frac{\Delta H^\circ}{2.303RT}. \quad (3)$$

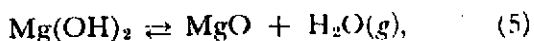
This reaction has a unique CO<sub>2</sub> pressure corresponding to any temperature. Such a reaction is referred to as a *carbon dioxide buffer*. Because  $\Delta S^\circ$  and  $\Delta H^\circ$  are generally only very weak functions of temperature, we can write

$$\frac{\partial \log p_{\text{CO}_2}}{\partial (1/T)} = \frac{-\Delta H^\circ}{2.303R} \quad (4)$$

which is effectively a constant over a temperature range of a factor of two or more.



An illustration of a water buffer would be



and similarly for other hydrous minerals of interest.

In general the halogen acids are formed by reactions involving atmospheric water vapor: a simple example would be



However since we postulate atmosphere-lithosphere interactions for all gases, we are in fact solving equation (6) *simultaneously* with water buffer reactions such as (5) above. These systems of two equations in two unknowns are in principle soluble, but frequently give answers which are plainly irrelevant to Venus. The crucial points we must consider are:

1. An acceptable atmospheric model must be capable of explaining simultaneously the abundances of all observed gases within a narrow range of temperatures and pressures.
2. Because of our a priori ignorance of the mineralogy of the surface of Venus, we must consider *every* buffer reaction for which the thermodynamic data are known.
3. We will regard as unsatisfactory any atmospheric model in which blatantly incompatible mineral assemblages are predicted by buffers of different gases. Should a certain  $\text{CO}_2$  buffer require the presence of  $\text{Fe}_2\text{O}_3$  under conditions in which an independently derived CO buffer requires the presence of elemental Fe, we would be compelled to reject the entire suite of "agreeing" reactions as unacceptable.

This is not to say that we absolutely require that all the minerals participating in a set of simultaneous buffer reactions must be capable of coexistence in intimate contact. This would be equivalent to requiring complete geochemical uniformity of the entire surface of Venus, an assumption which virtually all geochemists would regard as completely untenable. However, should such a completely compatible buffer system with the ability to regulate the  $\text{CO}_2$ , CO,  $\text{H}_2\text{O}$ , HCl, and HF abundances at the observed levels be found, it would be most warmly received.

4. Once we think we have found a set of reactions which provide compatible buffers for all the observed gases in a narrow temperature and pressure range, then we must use the derived surface temperature and pressure to calculate the abundances of

literally hundreds of gases which have *not* been observed on Venus. We then compare these predicted gas abundances with the observational upper limits on these gases as determined by careful searches for absorption features in infrared and ultraviolet spectra of Venus. Should we find an otherwise satisfactory model which, for example, predicts  $10^4$  times more methane than the spectroscopists will allow, we must discard this model.

5. Once we know the temperature and pressure on the surface from the discovery of a wholly consistent model, we then may look at the possible melting or volatilization of surface materials, paying particular attention to the most abundant elements and the most volatile and fusible minerals of rarer elements. Because of the very high surface temperatures, we may find that traces of gases such as  $\text{FeCl}_2$ ,  $\text{HgI}_2$ , arsenic and antimony sulfides, etc. would lend a peculiar pungence to the lower atmosphere even more memorable than that due to the traces of HCl and HF found above the clouds.

6. It is clear that at high surface temperatures there will be evaporation of some material that is much too involatile to be present as gases at observable ( $T < 240^\circ\text{K}$ ) levels. In other words, clouds of what may be described as "volcanic sublimates" must form. We hope to be able to say what materials are plausible cloud constituents.

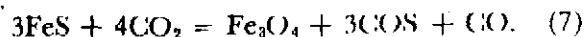
7. Finally, once we have discovered a consistent set of buffer reactions, we find we also have begun to assemble a list of minerals that may be present on the surface. And with sufficient relevant data on the mineralogy of the surface, we may begin to guess at the petrology. I claim that the best data currently available on the geochemistry and petrology of Venus are our infrared observations of the atmosphere above the clouds.

## Results and predictions: surface conditions

The most important single conclusion of present geochemical models of Venus is that there are two rather well-defined regions of temperature and pressure within which the observed atmospheric composition can be explained in terms of known chemical reactions with surface rocks. One such pressure-temperature region is on a narrow band connecting the points (190 bars,  $630^\circ\text{K}$ ) and (31 bars,  $595^\circ\text{K}$ ) on a plot of  $\log P$  vs  $1/T$ . In this region Mg-bearing carbonates participate in the  $\text{CO}_2$  buffer reactions and the CO abundance is regulated by  $\text{CO}_2 + \text{C(gr)} \rightleftharpoons 2\text{CO}$ , the graphite precipitation equilibrium.

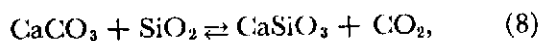
Several reactions are available to serve as  $\text{H}_2\text{O}$ , HCl,

and HF buffers. The only difficulty occurs when one attempts to account for the observational failure to detect any sulfur compounds in studies of the Venus infrared spectrum. The most stable sulfur-bearing gas, COS (carbonyl sulfide), can be minimized in abundance if the reaction regulating its pressure is

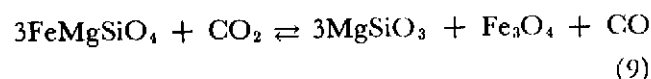


Even the amount of COS predicted by this reaction,  $\text{COS}/\text{CO}_2 \approx 3 \times 10^{-6}$ , is already some ten times higher than the spectroscopic upper limit on COS above the clouds. We have three possible choices for explanation of this curious result: either there are errors in the thermodynamic and spectroscopic data, or there exists a mechanism for removing sulfur from the atmosphere below the visible clouds, or the crust of Venus is devoid of sulfur. Perhaps the least unpalatable of these alternatives is the second, but none can be conclusively dismissed at present.

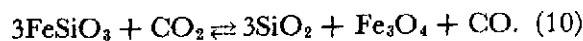
The second possible pressure-temperature point is at  $748 \pm 20^\circ\text{K}$  and  $120 \pm 20$  bars. Here the  $\text{CO}_2$  buffer is the calcite decarbonation reaction



and the CO abundance is controlled by



or



It is interesting that the oxidation state of the lithosphere of Venus is found to be the same as that of Earth's upper mantle. This second pressure-temperature point is of extraordinary interest because of the fact that two completely independent estimates of the surface temperature and pressure, made by analyses of the wavelength dependence of the apparent temperature of Venus at radio wavelengths, find  $770 \pm 25^\circ\text{K}$  at  $95 \pm 20$  bars and  $790 \pm 20^\circ\text{K}$  at  $110 \pm 15$  bars, respectively. Very recently the Soviet Venera VII probe has successfully penetrated the atmosphere of the planet and provided a direct (albeit crude) measurement of the surface temperature:  $747 \pm 20^\circ\text{K}$  at a pressure calculated to be  $90 \pm 15$  bars. The consensus of recent work is that the surface temperature is  $\sim 750^\circ\text{K}$  at a total pressure of  $\sim 100$  bars.

There is again one uncomfortable fact about this model for Venus: it is a near certainty that the predicted COS abundance is fully one hundred times larger than the spectroscopic upper limit! No matter what model we prefer for Venus we must account for the absence of detectable amounts of gaseous sulfur compounds. It is extremely unlikely that the data are

in error by this large a factor: a factor of ten error is barely credible. How then can we either remove sulfur from the atmosphere or from the entire crust of the planet?

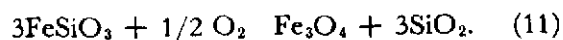
If a chemical mechanism for precipitating sulfur from the atmosphere is required, then there must be in the lower atmosphere a volatile chemical agent capable of forming an involatile sulfur compound at some temperature intermediate between the surface temperature ( $\sim 750^\circ\text{K}$ ) and the visible clouds ( $\sim 240^\circ\text{K}$ ). Nearly as satisfactory would be a demonstration that photolytic decomposition of relevant sulfur compounds proceeds so rapidly near the visible clouds that COS,  $\text{H}_2\text{S}$ , etc. are irreversibly converted to unobservable materials such as solid sulfur. If the former is true, then a thermodynamic study of possible cloud-forming condensates would be necessary. If the latter is to be believed, then it must be shown that all the compounds actually observed in the Venus atmosphere are either more resistant to ultraviolet photolysis than these sulfur compounds or are regenerated by recombination reactions as rapidly as they are photolyzed.

Alternatively we may propose an origin or evolution for Venus which results in complete loss of sulfur from the crust of the planet. Plainly such an alternative is much less attractive and would be employable only as a last resort.

## Surface composition

One result of these geochemical models for atmosphere-lithosphere reactions is the identification of certain buffer reactions that are compatible with the observed atmospheric composition. These buffer reactions, in turn, provide us with a list of plausible minerals which may be present on the Venus surface. The most important single feature of these models has been the apparently essential role of  $\text{SiO}_2$  as a pure phase. The existence of free quartz strongly suggests that the crust of Venus, like that of Earth, is a geochemical differentiate rather than a "primordial" material in which, as in meteorites,  $\text{SiO}_2$  is virtually impossible to find in uncombined form, and is largely tied up in ferromagnesian silicates.

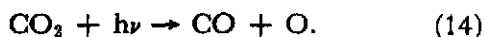
Simultaneously, we find evidence that the oxidation state of the crust of Venus is closely similar to that in the upper mantle of Earth, in that ferromagnesian silicates with  $\text{Fe}/(\text{Fe}+\text{Mg}) \approx 0.2$  coexisting with magnetite,  $\text{Fe}_3\text{O}_4$ , determine the oxygen fugacity via the schematic equilibrium



Here  $\text{FeSiO}_3$  is not present as a pure phase, but as a

pound. Clouds containing the less volatile materials Hg, Hg<sub>2</sub>Br<sub>2</sub>, Hg<sub>2</sub>I<sub>2</sub>, HgS, As<sub>2</sub>S<sub>3</sub>, Sb<sub>2</sub>S<sub>3</sub>, etc. are plausible candidates for lower-lying cloud layers. It is interesting to note that even the rare element Hg is abundant enough in the crust of Earth so that degassing would provide roughly 1 gram of mercury per cm<sup>2</sup> of surface area of the planet.

*Upper atmosphere.* At high altitudes the chemical behavior of the atmosphere is dominated by the photochemistry of CO<sub>2</sub>. The primary photolysis reaction is



The ultimate reaction for recombination of CO and O is



where *M* represents a third body capable of absorbing a portion of the recombination energy of CO + O as internal excitation. Important side reactions include the recombination of two O atoms to make O<sub>2</sub>, the formation of O<sub>3</sub> (ozone) by reaction of O<sub>2</sub> with O, and the photolysis of O<sub>2</sub> and O<sub>3</sub>.

One difficulty with this scheme is that the reconstitution of CO<sub>2</sub> from CO and odd oxygen (O or O<sub>3</sub>) is quite slow, and net destruction of CO<sub>2</sub> should occur until an essentially CO-O<sub>2</sub> atmosphere is developed. Such is not the case, and some mechanism must be found either to recombine CO and O in situ in the upper atmosphere or to mix the atmosphere on a time scale of hours all the way down to the cloud tops, where surface-catalysis may provide adequate recombination rates.

Of observed species in the Venus atmosphere, HCl is by far the most photolabile. It may contribute most of the hydrogen observed in the exosphere by the Mariner V Ly- $\alpha$  photometer. Photolysis of water vapor greatly complicates the picture, since numerous species containing hydrogen must be considered at all altitudes. Study of the upper atmosphere of Venus has reached the point where a new round of spacecraft observations of the turbopause region are needed. Dual-frequency ratio occultation experiments are capable of returning much useful data on this difficult region where the electron number density is decreasing exponentially with depth and where the refraction of radio waves by the neutral atmosphere is still exceedingly small. In situ mass spectrometric probing of the upper atmosphere, although still several years in the future, must be regarded as a necessity.

## Conclusions

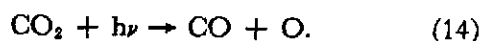
Since the principal reason for studying the Venus atmosphere is to gain a general knowledge of those effects which are obscured and complicated by various mechanisms peculiar to Earth, it is important to point out that study of Venus also introduces some new complications. Fortunately the basic information we are after is not likely to be obscured by any known or anticipated complexities, and we may confidently expect parallel study of the atmospheres of Earth, Venus, Mars, and Jupiter to be fruitful. In particular, Venus may assist us in understanding the geochemistry of the volatile elements, the origin of planetary atmospheres, the dynamics of a possible planet-wide Hadley cell circulation regime, the physical significance of the much-used but little-understood concept of eddy diffusion, and mechanisms for recombination of photolysis products which may be of use in understanding Earth's upper atmosphere.

Perhaps the most intriguing aspect of Venus exploration is the prospect of discovering more about the origin and evolution of the terrestrial planets, particularly why Earth and Venus diverge so profoundly in nature. Theories of the origin and history of our solar system must be found which account not only for the overall compositions of these planets but also for the origin and stability of their atmospheres, their surface conditions, rotational angular momentum, possession or lack of satellites, and so on. Many features of a general theory of planetology can now be anticipated with some degree of certainty, but the formulation of such a theory is still many years in the future.

Within the next few years we may anticipate further scientific investigations of Mars (by the Mariner Mars 1971 spacecraft), Jupiter (by Pioneer F and G and Grand Tour missions), and Mercury (by the 1973 Mercury-Venus flyby). To date, exploration of the atmosphere of Venus has been largely the work of Soviet scientists, whose Venera IV, V, and VI spacecraft have entered the Venus atmosphere, and whose Venera VII probe has recently succeeded in landing on the planet's surface. Crucial areas for future Venus research by both the Soviet Union and the United States include: (1) detailed chemical analyses of the lower atmosphere by a deep-entry probe; (2) mapping of the planetary-scale circulation by balloon-borne "floaters" carrying radio transponders; (3) mass spectroscopic analyses of the upper atmosphere over a wide altitude range; and (4) geochemical and geophysical investigations of the surface of the planet.

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HES AIRCRAFT COMPANY

## 2.5 INTERDEPARTMENTAL CORRESPONDENCE

TO: Distribution D  
ORG:

CC:

DATE: 9 October 1972  
REF. HS507/0220SUBJECT: Trip Report, DLBI Meeting  
with I. I. Shapiro at MIT on  
29 September 1972FROM: D. M. Newlands  
ORG.BLDG. 376 MAIL STA. 9115  
EXT. 83788

Ref: Wind Speeds in Lower Atmosphere of Venus: Status Report on Possible Measurement via Differential VLBI Tracking of Entry Probes; Irwin I. Shapiro, MIT, May 1972.

A meeting was held at MIT on 29 September 1972 to discuss Differential Very Long Baseline Interferometry (DLBI). Pioneer Venus Orbiter Radio Science was also discussed briefly. Present were:

Dr. Irwin I. Shapiro, MIT  
A. M. Lauletta, HAC  
L. K. Acheson, HAC  
D. M. Newlands, HAC

On the subject of DLBI for Pioneer Venus, Dr. Shapiro indicated that he has done essentially no further work since he wrote the referenced paper "one weekend in May." He has a graduate student who is working on the required error analysis but to this time, the student has gone no further than digesting what is already in Shapiro's paper.

Shapiro believes that the critical problem in the error analysis is a determination of the spatial and temporal noise spectrum of the interplanetary plasma. This is principally a geometry problem. The signals from all probes arriving at any one ground station essentially enter through the same portion of the Earth's ionosphere and atmosphere. Similarly, the signals emitted by any one probe (which reach all Earth stations) leave through the same portion of the Venus' atmosphere. In both these cases, the same portion is interpreted to mean within the Fresnel zone. However, between Venus and Earth in the interplanetary plasma, the separation between signals leaving the same probe or arriving at the same ground station is of the same order as the separation between probes and between ground stations. This separation (about 2000 km) far exceeds the Fresnel zone size (about 100 km). Shapiro is not sure how he will resolve this problem. He feels the best he can do is bound the problem. In any event, it does not appear that the error analysis will be available to us in time to allow a system trade between DLBI and the wind drift radar instrument.

Trip Report, DLBI Meeting  
with I. I. Shapiro at MIT on  
29 September 1972

Ref: HS507/0220  
Page: 2

The ERP requirement for DLBI is not expected to size the transmitters. Shapiro has based his analysis on several hundred flux units (1 flux unit =  $10^{-26}$  w/m<sup>2</sup> Hz) which is a realistic assumption based on S/C communication requirements. The critical requirement at each DSS is that all the LO's have common noise. That is, each receiver LO should be derived from the same standard and the LO chains should share as many stages as possible. He also emphasized the need for keeping all links within 50 or 100 KHz to eliminate frequency dependent effects which would not difference out.

Dr. Shapiro stated that the required oscillator stability was 1 part in  $10^6$  or  $10^7$  over half an hour. The basis for this number is so that the oscillator is not the principal error source. This should be compared with the APL stable oscillator development which has 1 part in  $10^9$  as a goal. When questioned further, he stated that non-coherent signals (MFSK) should not bother DLBI.

Dr. Shapiro intends to propose a dual frequency orbiter radar for use in measuring gravitational contours. The differential absorption between S and X band signals will be used to infer the amount of atmosphere below the orbiter. He is sending us a paper on this subject. Shapiro would like global coverage for this experiment. He does not subscribe to the theory that since the North and South hemispheres are probably mirror images, coverage of only one hemisphere is sufficient. He stated that he was strictly a theoretician and that Dr. Pettingill provided the instrumentation knowledge.

He was not able to relate the listed hardware to the listed Orbiter RF science experiments in the SSG. He stated that the bistatic radar was definitely S/C to Earth. He did not know the purpose of the listed X-band receiver. He did not believe it was included for his dual frequency radar experiment discussed above since the experiment was not fully formulated when the SSG was meeting.

  
D. M. Newlands

/nn

## 3.0 INTERDEPARTMENTAL CORRESPONDENCE

TO: A.M. Lauletta, Jr.      CC: See distribution.  
ORG: 44-23  
SUBJECT: A Proposed ESRO Spectrometer  
Experiment for the Venus  
Orbiter

DATE: 23 October 1972  
REF. HS507-0237

FROM: L. K. Acheson  
ORG. 40-91

BLDG. 376      MAIL STA. 11141  
EXT. 8-1086

On Friday, October 13, Professor Andre Gaston Monfils of the Universite' de Liège, Cointe-Sclassin, Belgium, gave a talk on a "Spectrometric Device for the Analysis of Light Emission from a Venus Orbiter" at a Space Optics meeting in Santa Monica, sponsored by the International Commission for Optics\*. I attended this talk and had an extended discussion with Professor Monfils afterward.

Some current ESRO thinking on the desired characteristics of a UV spectrometer for the Venus Orbiter was obtained.

Key points:

- o Monfils believes that a basic spectrometer to make the desired measurements can be built at a weight of about 4 kg (8.8 lbs). He has had difficulty convincing people (in Europe) that one can build a spectrometer for such a low weight.
- o It has been taken as a ground rule for the design that the spectrometer axis is lined up with the spin axis (a polar orbit is assumed with a mid latitude periapsis and the spin axis normal to the ecliptic).
- o A spin scan mode is currently envisioned which would utilize a mirror positionable at a 45 degree angle to the spectrometer axis to provide a field of view 90 degrees to the spin axis for an imaging scan.

Attached are:

- 1) an abstract of the paper as given in the preprinted program,
- 2) a summary of the presented talk from my notes, and
- 3) notes on our subsequent discussion.

An evolution in the spectrometer concept is clearly evident.

*L. K. Acheson*

L. K. Acheson

LKA:vv

A-105

Attachments: 1 = 3 pp.  
2 = 3 pp.  
3 = 1 p.

\* Congresses are held every three years with different themes. This was the 9th meeting (ICO-IX) and was only the 2nd to be held in the U.S. (ICO-IV was held in Cambridge, Massachusetts in 1956.)



## A SPECTROMETRIC DEVICE FOR THE ANALYSIS OF LIGHT EMISSION FROM A VENUS ORBITER

### A. Monfils

ESRO is considering the possibility of launching a Venus Orbiter space probe that would be placed on an eccentric orbit around the planet. The description of a spectrometric device is given. This apparatus is aiming at the recording of the various emissions likely to be present in the high atmosphere, as twilight, dayglow or even some kind of auroral emission. A consideration of the basic requirements leads to the following specification :

1. The spectrum does not need a high resolution. Bandpasses of 20A are largely sufficient, except for a few bands whose precise rotational profile must be known.
2. The probe is spin stabilized and the optical axis of the spectrometer parallel to the spin axis. This allows continuous observation during the crossing of the atmospheric profile by the optical axis. Unfortunately, the image of the planet is rotating with respect to the spectrometer.
3. The phenomena to be analysed are not changing at a fast rate. Time is a factor to be exploited and the information may be accumulated from orbit to orbit.
4. Telemetry channels, weight and power are critical. Two different solutions are proposed and described.

#### I. Multiple Band-Pass System.

This system has been studied a few years ago by Courtès and Viton<sup>(1)</sup> and was proposed

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(1) Courtès and Viton : Ann. Astrophys. 28 (1965)  
pp. 691-697.

as the basic principle of the French-Belgian-Swiss proposal of Large Astronomical Satellite once projected by ESRO.

It is based on the integration of the optics of the spectrograph and of the telescope. It is the image of the primary that is dispersed and not an entrance slit as usual. The image of the planet will be formed on the grating, whose symmetry is compatible with the spin motion. The proposed modified solution is shown to have mainly two advantages :

- a large throughput may be obtained in favorable cases, such as the present one

- for a given luminosity, the mounting is light and may hold three to four detectors.

The main drawbacks are a limited resolving power and a linear structure.

This solution appears as ideal if an average resolution of 5A is acceptable.

## II. Association Czerny-Turner-Fabry-Perot

A completely different solution may be found starting with a Czerny-Turner monochromator preceded by a conventional telescope and comprising a Fabry-Perot étalon on one of the parallel beams.

When the F.P. is parallel to the beam, it is not active and the low-resolution part of the spectrum may be recorded. When a higher resolving power is necessary, the F.P. is turned and is ready for the scanning of bands of a few tens of A with a bandwidth of the order of one angström.

The spectral region extending between 1000 A and 8000 A may be scanned using four gratings of the highest possible number of lines per mm and four detectors of calculated working function, if it is split into the following bands :

A :	1.000 to 2.000 A	B :	1.650 to 3.300 A
C :	2.500 to 5.000 A	D :	4.000 to 8.000 A

To each corresponds an optimized grating and photocathode :

A :	6000 1/mm	CsI photocathode
B :	3600 1/mm	RbTe "
C :	2400 1/mm	bi-alkali photocathode
D :	1500 1/mm	tri-alkali "

The Fabry-Perot to be coupled with each scanned region must have a finesse of 14, 23, 35 and 56 for each upper limit respectively. This, in fact, corresponds to the same surface quality, and is technically accessible. The four bands may be scanned by four Czerny-Turner monochromators of very short focal distance (6 cm), mounted with  $f/4$  off-axis parabola.

It may be shown that one and the same motor may be used for moving the four gratings, and another for the four Fabry-Perot.

The total package is very compact, mounted with 8.4 cm DF telescopes, and has a total throughput of

$$4 \times 3.35 \times 10^{-4} \text{ cm}^2$$

This is quite acceptable for a total weight (electronics and motors included) of less than 2 kgs. The total scanning time is 5 minutes for a 3% precision of a spectrum consisting of spectral features of 1 kR intensity. This allows 1 to 5% of the spectrum to be scanned at 1A bandpass.

### Conclusion

Two very different solutions for the recording of airglow spectra of Venus are proposed. One is based on an integrated telescope-spectrograph optics (B.P.M.) which allows a very clear optimisation of the luminosity/weight factor. The second postulates the miniaturization of C.T. Spectrograph to a degree not yet used, to our knowledge. In particular, this miniaturization, coupled with the optimized use of gratings and detectors, allows also a very high ratio of luminosity/weight. It is more sophisticated but more powerful.

A SPECTROMETRIC DEVICE FOR THE ANALYSIS OF  
LIGHT EMISSION FROM A VENUS ORBITER

A.G. Monfils - 13 October 1972

There is good support for exploring Venus at the end of the decade. We will be mainly dealing with the philosophy of what type of spectrometer should be mounted on a deep space planetary probe. Because of the constraints of payload weight, the design is severely restricted.

The conditions assumed are:

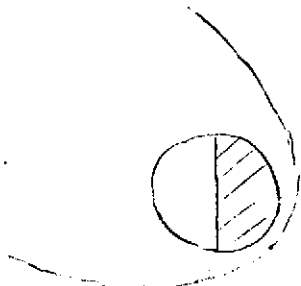
- 1) A probe ejected into orbit around Venus.
- 2) Rapidity of observation is not needed; there is a long time to make observations.
- 3) Weight, telemetry, and power are all critical.
- 4) Probably the probe will be spinning about the optical axis, which requires the use of holes rather than slits.

Objectives of the measurements are:

- 1) Identification of atmospheric minor constituents, which require a high resolution of a few Å.
- 2) Temperature profiles and scale height measurements, which require point openings or holes with a space resolution of 0.01 radian.
- 3) Determination of emission mechanisms, for which 10's of Å are sufficient.
- 4) Mapping of the cloud cover in UV; which requires hole apertures.

Thus we need a very lightweight device, having a telescope, with a hole aperture and high resolving power. We also need a spectral range as wide as possible. We don't just want to stick to UV.

A typical orbit is shown. Perigee might be 300 km.



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The instrument proposed is based on Fabry-Perot optics, with a 90 mm focal distance. Why so small? Where weight is so important, a specific figure of merit is

$$SFM = \frac{LR}{W} \sim \frac{r\Omega n}{F^2}$$

where:  $r$  = radius of entrance hole

$n$  = number of detectors

$\Omega$  = angle subtended by grating

$F$  = focal distance

The important thing here is that  $F$  appears as the square and that ideally one should use spectral devices with  $F$  as small as possible. To receive wide spectral ranges one multiplies the number of monochromators.

The use of four monochromators is proposed covering the regions:

- (1) 1000 to 2000 Å
- (2) 1650 to 3300 Å
- (3) 2500 to 5000 Å
- (4) 4000 to 8000 Å

Gratings with as many as 6000 lines/mm can be used for the 1000 to 2000 Å region, and a 1500 1/mm grating is useful up to 8000 Å.

A drawing of the instrument is shown in Figure 2.

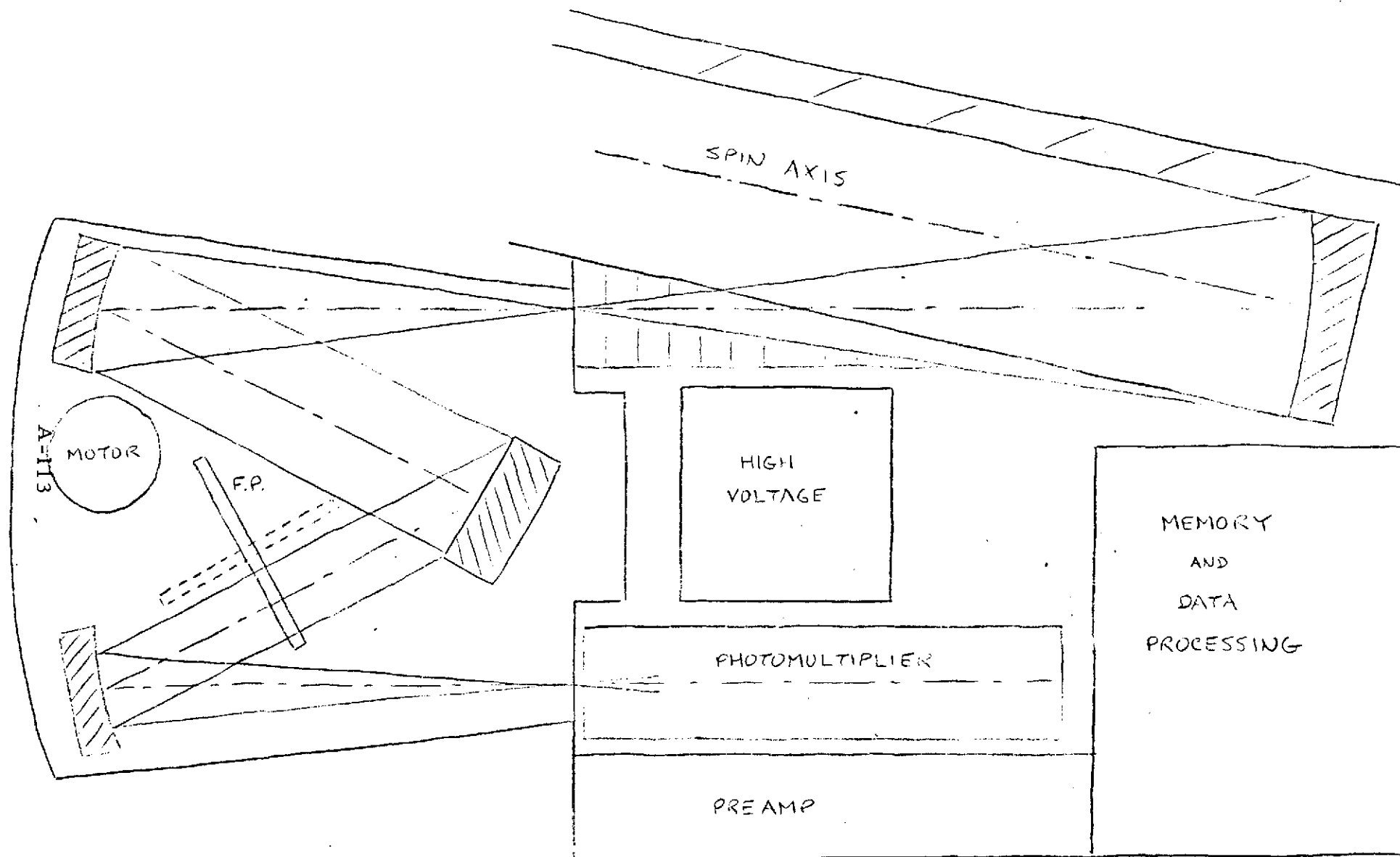
It is possible to have a very sophisticated data handling system for very low weight and size, with new techniques.

In conclusion, a basic condition for choice of focal distance is that the weight of the electronics should be about the weight of the optics, and considering the optics the weight of the telescope should be about equal to the weight of the spectrometer.

Thus  $W_E \approx W_O$ .

and  $W_T \approx W_S$

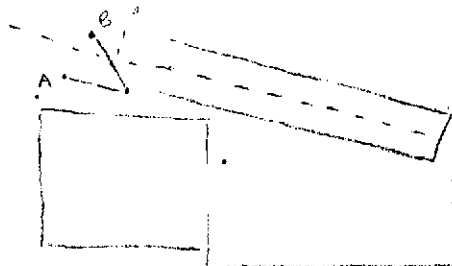
It is easy to keep the last weight within one kg, which means a total weight of 2 kg for the electronics, 1 kg for all telescopes and 1 kg for all spectrometers, for a total of 4 kg. One can use a common motor for all four gratings.



UV/OPTICAL SPECTROMETER

## DISCUSSION WITH PROFESSOR MONFILS

Originally there were two ESRO optical experiments proposed for the Venus Orbiter, one was Monfils' spectrometer and the other was an imaging experiment by A. Dollfus in Paris. The latest ESRO thinking is to combine these. One can provide a scanning mode to Monfils' instrument by means of a two-position mirror in front of his telescope as shown below, which would provide a beam at right angles to the spin axis (i.e. the telescope axis) when in position B, and along the spin axis when in position A.



Additional weight of this mode would be very small. A very complex data handling logic can now be provided in a very small space, and since measurements will be only taken near periapsis, the rest of the orbit is available for data transmission.

The biggest problem Monfils has had has been convincing the people in Europe that one can build a spectrometer for the very small weights that Monfils is talking about. He is also asked if he has flown any instruments and in Europe he hasn't had any opportunity to do so.

He asked me if Barth was planning to propose for the orbiter, and I said that on the basis of our talks with Stewart I thought he was. Monfils made reference to the large weight of the instruments that Barth has been using.

Asked about the overall size of his instrument, he said it was about the size of four thick telephone directories. Power is about 4 watts.

Monfils emphasized, however, that what he had presented was not a specific proposal but rather a philosophy. A-115

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#### 4.0 INTERDEPARTMENTAL CORRESPONDENCE

TO: Distribution "D"	CC:	DATE: 2 November 1972
ORG:		REF. HS507-0253
SUBJECT: Notes on McElroy Science Briefing - 20 October 1972.		FROM: L. K. Acheson
		ORG:
		BLDG. 376 MAIL STA. 11141
		EXT. 81086

Science consultant Michael B. McElroy spent two days at Hughes on 19 and 20 October. The following notes summarize a general science briefing (question and answer session) held Friday morning 20 October, with about a dozen Pioneer Venus team members present.

#### Orbiter Discussion

Tony Lauletta opened the briefing by posing the question of why an initial periapsis near the evening terminator is undesirable, as stated in the SSG report. McElroy thought there might be two reasons: (1) the terminator is an unusual region for many atmospheric effects, and (2) most of the interesting things are on the day side. He asked whether periapsis was moving into the dark side after insertion.

McPherson stated that after orbit insertion, there would be from one to three weeks before periapsis would move into complete eclipse, where it would remain for half a Venus year (over 100 days).

McElroy reviewed the kinds of measurements the orbiter is set up to measure: (1) neutral atmosphere measurements don't care where periapsis occurs, (2) for the ionospheric measurements, the terminator is an atypical situation, (3) measurements of surface geometry don't care whether one is on the day side or the night side, (4) for measurements of the solar wind interaction, an altitude of 500 km at the subsolar point is of interest. Ideally, the initial periapsis should be as high as 500 km and then be dropped down.

The question was raised as to whether a lower periapsis wouldn't be adequate since the orbiter would pass through the 500 km region on its way to periapsis. McElroy replied that a lot of plasma related experiments are interested in passing through the plasmopause as slowly as possible and thus would like to have periapsis at that altitude. However, priorities for the orbiter do not make this the prime mission; in fact, it is not certain that the particle's and fields people are going to get on the orbiter -- most of their experiments have been relegated to "other candidate instruments."

McElroy raised the question of whether the consideration of high inclination angle orbits wasn't governed by the radar mapping people, and wondered whether a polar orbit wasn't bad for the occultation experiments.



McPherson said that with a polar orbit, you have a set of occultations near periapsis and a smaller set near apoapsis. With an ecliptic plane orbit, there are two occultations every orbit.

McElroy raised the question of whether there might also be interest in UV solar occultations. He felt that he could see a basic conflict. Earth occultation experiments are a very important part of the orbiter (for both high altitude and low altitude temperature studies), and there will be strong opposition from experimenters if the mission is not optimized for these measurements. But radar mapping is bad in the ecliptic plane, so some compromise will probably have to be made.

Dick Cheng suggested that it is probably necessary at this time to design the spacecraft for a range of inclinations, e. g., 45 degrees to 90 degrees. McElroy replied that the more flexibility you can build in, the better, if it can be added at insignificant cost. If one were homing in on one orbit at the moment, he would pick 45 degrees.

McPherson pointed out that with a 45-degree inclination orbit, there is very little gain in the number of occultations, while there is considerable degradation in the radar mapping capability. Furthermore, checking earlier Hughes studies reported in the proposal shows that there is about a sixty day occultation season near periapsis and six days near apoapsis for the polar orbit assumed in the proposal.

McElroy felt that if there were indeed this many occultations, then perhaps there was not a serious conflict and the polar orbit would be acceptable.

The question of where periapsis could be located was raised. McPherson stated that it could be located at 20 to 30 degrees latitude for a Type II trajectory and at either the equator or the pole for a Type I trajectory.

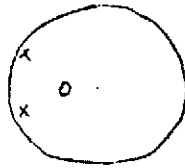
McElroy said that either a mid-latitude periapsis or periapsis at the equator is OK, but that one doesn't want periapsis at the pole. McPherson pointed out that with periapsis at the equator, one gets less radar mapping coverage than at mid-latitudes. McElroy felt that the principal consideration should be to get as long an observation time as possible.

McElroy expressed the belief that the mission will go toward a higher inclination orbit, but the dark side presents a problem.

Dave Newlands asked whether the radar altimeter was the sole factor in wanting the high inclination orbit, and if the desired orbit would be quite different if the radar altimeter was not flown. McElroy replied that he didn't think the high inclination orbit presented too serious a problem for the other experiments, and that he thought the radar altimeter will be a significant experiment for the orbiter.

McElroy is not sure to what extent the particles and fields people will attempt to take over the spacecraft (they want a highly eccentric, loose orbit), but McElroy believes this should be primarily a planet oriented mission.

McPherson pointed out that one has the following choice of initial periapsis locations on the sunlit side of the planet:



McElroy immediately said that the equatorial location was the best choice, even at the expense of degrading the radar coverage. He expressed the belief that the orbiter was primarily intended for upper atmosphere measurements, with radar mapping secondary.

Lauletta suggested that this was probably true if ESRO has its way, but not if the US has the major say. McElroy said he would guess that from a US perspective, the upper atmosphere group would dominate, and that he didn't know about ESRO. It would depend on who is on the NASA/ESRO Orbiter SSG.

Lauletta brought up the question of spin-axis orientation. McElroy has talked to Hunten concerning this. Hunten feels it is a very difficult problem, and he doesn't want to state a preference. McElroy stated that he does not wish to either.

McPherson observed that for the planetary mapping experiments, one wants the spin axis parallel to the surface, and for the velocity pointing instruments, one wants the spin axis along the velocity vector.

McElroy pointed out that questions of spin-axis orientation are of interest in the Atmosphere Explorer spacecraft, and suggested that we might talk to Bill Hanson at the University of Texas in Dallas. He has a plasma probe experiment on AE and is chairman of the AE Science Team. He also has an upper atmosphere experiment on Viking.

Chris Thorpe asked if there were any other velocity critical experiments than the mass spectrometers. McElroy replied that the plasma temperature probe was also to a small extent. A different type of constraint occurs in the case of the solar plasma experiment where one wants to scan the sun.

Lauletta raised the question of spin rate. McElroy felt that 5 rpm is no problem for the atmosphere sensing instruments. The UV experiment might be the most sensitive, but Stewart has indicated there is no problem there. Even 10 rpm may not be prohibitive. Atmosphere Explorer has a 5 to 10 rpm capability. It also has a complete despin capability, but there has been no demand for this.

With regard to the required stability of the spin axis, McElroy said he couldn't give an answer off hand. He was not aware of any restrictions but there may be some.

McElroy felt there will be a lot of pressure to push the periapsis altitude down, even so far as to eventually kill the mission. McPherson pointed out that there is only a small additional altitude to be gained before overheating destroys the spacecraft. It was observed that from the first few orbits, one could get density data which would permit lowering perigee to the maximum safe level.

McElroy said that data on the structure of the upper atmosphere is entirely from Mariner 5 day side measurements. There is one atmospheric model that shows an extreme variation in temperature -- from 800 degrees on the day side to 250 degrees on the night side -- which could give extreme density variations. If periapsis is adjusted for the lowest safe night side operation, then one may be in trouble with a denser atmosphere when one comes out on the day side.

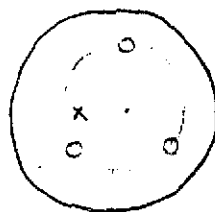
McPherson pointed out that we have the capability for changing periapsis at anytime in the mission.

McElroy mentioned that although the person responsible for the high temperature variation model is highly respected, McElroy thinks the model is no good. It is based on the assumption that the length of a day on Venus is 144 days. Above the clouds, however, the length of a day is four days (because of high rotational velocities in the upper atmosphere) and probably there is a variation in the length of a day throughout the atmosphere.

Regarding the question of how long one needs to keep periapsis at a given altitude, McElroy believes this needs to be very flexible. The argument for staying at low altitude for a long period may breakdown if it turns out that nothing is changing. The experimenters may get bored and want to go to high altitude where things are changing rapidly.

#### Probe Discussion

McPherson asked about the desired targeting of the small probes. McElroy said that since the small and large probes have a certain redundancy, one wants to spread them as much as possible. Also, one wants at least one at high latitude (50 - 55 degrees). There may be rapidly descending atmosphere currents in a narrowband of latitudes. McElroy thought that the pattern shown was a preferable one.



X LARGE PROBE

O SMALL PROBES

Leo Nolte pointed out that entry angle was also a factor in targeting, the lower the entry angle, the greater the heat shield requirements. There will be at least one shallow entry.

McElroy agrees with the SSG targeting of the large probe.

Nolte said that he had two general questions:

- 1) The question of the science factors affecting the descent rate, and
- 2) The question of the uncertainties and margins on the atmospheric models.

McElroy mentioned that he had just talked to Hunten regarding the parachute deployment problem. Hunten's attitude at first was who cares when the parachute comes on, then after more thought said that it would be very bad if one didn't start taking measurements until after the sun is extinguished.

The best information on the cloud cover is that it occurs at a pressure point of 0.2 atmospheres. If one is measuring before this point, then one will surely be seeing sunlight before it is extinguished. The altitude uncertainty is about  $\pm 2$  km.

Regarding atmospheric models, McElroy feels that the models are extremely good from the surface to 60-65 km. The uncertainties there are tied to the bottom few km, and possible holes on the planet surface. The probes should be designed for an extra 5 km of entry.

McElroy feels the mission would be a complete success if the probe survives to the nominal surface altitude. If there is a low cost (e.g., 1%) in designing it to go further, then it would be worthwhile, but not if it costs 20%. But McElroy feels it would be desirable to have an altimeter to know how far down the surface is if the probe doesn't survive.

McElroy said that a strange blip in the temperature atmosphere profile which Nolte had noticed is real (a 1 km dip at  $\sim 43$  km). This is a very interesting feature and one may want to go through this region slowly. Hence, this is a factor in ejecting the parachute. It may represent very dense clouds, and it is interesting that Lewis' postulated Hg layer is in this region. One might sense this altitude by either temperature or pressure. One should keep the parachute on until about 5 km beyond this region.

McElroy mentioned that he felt the mass spectrometer inlet condensible problem was a serious one and wondered how Hughes was going to handle this. Nolte said that we have not looked at the inlet design in any detail partly because of the NASA studies in this area. McElroy said that any system will have this as a requirement.

Nolte asked what science factors influence the small probe descent rate, and whether it was important for the small probes to survive to the surface.

McElroy said that it will still be a good mission if they don't survive to the surface, but that it is a question of cost. It is certainly desirable to survive to the surface.

Nolte pointed out that if one says that the large probe has priority, then we don't have sufficient weight margin for the small probes, and Nolte was wondering about backing off as much as 20 km from the surface.

McElroy felt that even 20 km would be acceptable.

Thorpe raised the question of how we know we are on the surface. Is it when the data ends?

McElroy said that yes, this was a problem, and he thinks one should have an altimeter, but that one should not complicate the small probes with an altimeter. McElroy said he would assume that you know enough about the atmosphere to tell whether you have reached the surface when the data ends.

Thorpe asked if it would be possible to switch off the high altitude experiment, such as the shock layer radiometer and the hygrometer at a given altitude to conserve power. McElroy thought this was possible for the two experiments mentioned but that the aureole extinction detector might want to go all the way. The "other candidate instruments" all go all the way.

Regarding parachute blockage, McElroy feels that 10% obscuration would not be a problem as long as the sun is not observed.

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L. K. Acheson

/nn

## 5.0 INTERDEPARTMENTAL CORRESPONDENCE



TO: Distribution D  
ORG: NASA/ARC  
S.D. Dorfman

DATE: November 8, 1972  
REF. HS507-0260

SUBJECT: Science Discussions  
Nov. 1 and 2, 1972


FROM: LKAcheson/AMLauletta  
ORG. 44-24

BLDG. 376 MAIL STA. 11141  
EXT. 8-1086/8-2479

The writers visited the Washington D.C. area on November 1 and 2, 1972 to discuss Pioneer Venus science requirements with members of the science community and Goddard.

Arriving late Wednesday afternoon, we held meetings with Drs. Hanson, McElroy, and Delsandro that evening. The next morning we met with J.W. Bryan at Goddard. Both discussions are attached in addition to a paper by Bryan and Richter.

Later Thursday we left for New York to attend a meeting on Friday, Nov. 3 with Ames, Martin, TRW and Singer-Kearfoot relating to the Singer-Kearfoot Winddrift Radar study. A separate report will be issued on this meeting.

  
A. M. Lauletta

  
L. K. Acheson

Attachment: I 3pp  
II 4pp  
III Preprint X 551 71 494 GSFC

AML:LKA:vv

## 5.1 DISCUSSION WITH W.B. HANSON

On Wednesday evening, November 1, a meeting was held with William B. Hanson, head of the Atmosphere Explorer science team (and head of the Planetary Sciences Department at the University of Texas, Dallas). Also present were Mike McElroy, who had suggested the desirability of such a meeting and a third AE scientist, Dr. Delsandro from Harvard. The meeting was held in Washington D.C. where the above three scientists were attending a series of AE meetings at Goddard, and where we were visiting Goddard the following day to discuss the altimeter/microwave radiometer experiment for the orbiter with J.W. Bryan.

Object of the meeting with Hanson was to discuss the spin axis/orbit preferences of the Pioneer Venus upper atmosphere instruments and the possible utilization of AE instruments in the Atlas Centaur payload.

Hanson's initial reaction was that at first sight it might be attractive to consider the AE instruments. However, these instruments were developed for the AE system and would require a more detailed review to determine their specific application to Pioneer Venus. AE employs a much higher data rate (16 Kbs) than PV, as an example.

There are five mass spectrometers on AE: a Bennett Tube ion mass spectrometer, two magnetic mass spectrometers (one neutral particle and one ion) and two quadrupole mass spectrometers, both neutral particle. Almost all start from mass one and go at least to 44, some go higher.

All of these are mounted peripherally, pointing normal to the spin axis, and the spin axis is normal to the orbit plane. With this mounting one looks into the ram once every revolution. Hanson said at first that this is really the only way to do it, but later agreed that with a spinning axis normal to the ecliptic, one could mount the instrument along the spin axis for a polar orbit.

The spin rate utilized for these instruments on AE is four rpm ( $24^{\circ}/\text{sec}$ ). This is close to the maximum spin rate since one would like to be pointed within  $\pm 12^{\circ}$  of ram, and one second is about the minimum sample time. If you

A-125

go over 5 rpm you are pushing the limits. As a lower limit you don't want to go much slower than 2 rpm because of the loss of data. One would like the resolution to be small compared to a scale height, e.g. 1/3 of a scale height.

Typical telemetry for a mass spectrometer (for AE) involves 120 to 160 eight bit words/sec, i.e. over one Kbs of science data. Regarding command there are probably at least ten commands for one mass spectrometer.

Regarding allowable angle off the velocity vector, if the angle is less than 30 degrees, then a lot of experiments could accommodate to this, but if it is greater than 30 degrees then probably a lot could not. Hanson felt that maybe from the AE experience we will learn more about these limits. He pointed out that the sensitivity of ion spectrometers as a function of angle is not a simple cosine function. Probably some of the neutral spectrometers such as Spencer's might be able to operate even a little farther out than 30 degrees.

If one is restricted to a spin axis normal to the ecliptic and a polar orbit, then if perigee is at some mid latitude, Hanson felt that it would be desirable to cock the instrument slightly off the spin axis for best coverage.

Regarding the highest altitude at which it is desired to make measurements, Hanson said that with the AE instruments measurements were possible down to a particle density of about  $10^5$  particles/cm<sup>3</sup> for the neutral mass spectrometers, and he didn't know what that corresponded to on Venus. McElroy said that 500 km was the maximum altitude of interest on Venus. The question was raised as to whether the ion mass spectrometers didn't want to make measurements at higher altitudes. McElroy still felt that 500 km was the maximum but Hanson seemed a little doubtful. He indicated that one might be able to measure hydrogen ion densities to higher altitudes if it were desired.



The measurement requirements for the solar wind probes were brought up. McElroy said that measurements at a periapsis of 500 km on the day side were required. He didn't feel one needed to make measurements throughout an orbit. Hanson, on the other hand, did think that the experimenters would want to make measurements throughout the orbit, but he thought the required data rate was very low.

There are a total of 15 experiments on AE. There are a large number of write-ups on these instruments. Hanson suggested contacting Grimes or Spencer to see about getting experiment descriptions. McElroy will send us a report containing a brief writeup on each instrument, and we will decide from that the instruments on which we would like to have detailed data.

## 5.2 DISCUSSION WITH J.W. BRYAN (NASA/GSFC)

On Thursday, November 2, a meeting was held with J.W. Bryan at Goddard to discuss aspects of the radar altimeter and microwave radiometer experiments for the orbiter. Bryan is with the Mission Flight Analysis Department. He has authored several recent reports (Dec. 1971) on altimeters for both the Venus orbiter<sup>(1)</sup> and the large probe.

Bryan said that his primary interest was in a radar altimeter for the orbiter, and that he definitely planned to submit a proposal for this experiment when the AFO is released. He did not propose on the altimeter wind drift radar for the large probe, feeling that his work in this area was more as a consultant. He indicated he would welcome assisting Ames in this area if requested. Bryan wants to plot the terrain of Venus to some nominal accuracy, feeling that one should first do a coarse mapping, and then in later missions a more refined mapping,

We discussed a number of questions concerning the orbiter RF science requirements which Dave Newlands of Hughes had raised.

The first question was why Bryan thought that Ames treated the microwave radiometer and the altimeter as separate instruments when it was relatively easy to combine them as Bryan had proposed in his latest report. The only reason that Bryan could see was a possible desire to provide for separate experimenters. For Bryan, the surface temperature profiles were also of interest, and since his altimeter would be turned off 80 percent of the time, he thought it made sense to time-share the microwave radiometry measurements with it,

With regard to what you have to add to an altimeter to make a radiometer out of it, Bryan said that first you have to ensure a linear AGC in the receiver for radiometry since this is the only way to extrapolate temperature points. This can be used in the altimeter but is not independently required by it, although it would mean that reflectivity or radar cross-section measurements of Venus could be obtained in addition to altitude.

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(1) See attached report.

The second thing one needs is a hot load and a cold load for calibrating the radiometer. The hot load can be a carbon resistor in a thermal box. For a cold load one can simply point at cold space.

With regard to frequency selection it looks like S-band is the best place to operate. At X band the absorption is too high. Lower than S-band would also be fine but presents size and weight problems. Radar S-band frequencies are at 3000 MHz (10 cm), while communication S-band frequencies are at 2300 MHz (14 cm).

Bryan saw some problems in trying to time-share the communication and radar functions, since he was planning to use an earth reference (provided by the communications antenna) in keeping his radar antenna pointed at Venus, and would do the same thing in the radiometer mode. He felt one should get away from a common system.

With regard to the penalties for pointing off vertical for the altimeter, Bryan felt that if more were known about the planet, a coherent system would be designed for improved S/N, but we don't know enough to do this, and we can't live with an antenna that doesn't point right at the planet. If Bryan had his druthers he would have a despun stabilized platform.

The beamwidth in Bryan's design was 9 degrees. If one wanted to do a detailed mapping, a narrower beam would be desirable, but Bryan doesn't believe it is needed. With an Atlas Centaur booster, however, he would consider a narrower beam. Bryan's main restriction on beamwidth is that he wants the edges of the beam scan to scan at the equator to slightly overlap (i.e. 10-20%), so that the whole thing can be put together into a contiguous map.

Bryan considered an operating altitude from 400 km at perigee out to a maximum altitude of 1500 km. He feels that one has to fly solid state components, and that 10 kw is the highest power available at S-band, which limits the height.

Richter (Bryan's co-author in the orbiter altimeter/radiometer report) has just prepared an updated version of a report on enhanced microwave absorption in the lower atmosphere of Venus which he wrote in June 1971. Bryan will try to send us a copy. He said that the altimeter requirements don't really change as a result of the new data. Bryan feels that the range is too long for an FM chirp system to work and that a pulse system is required.

Ground based measurements really see only one side of Venus, and although the reflectivity is near unity for vertical incidence, it drops off sharply as one moves off vertical, so that the ground based measurements are good to about  $\pm 10$  degrees from the subearth point. R.L. Carpenter (from ground based measurements) has found that there appears to be at least one hill on Venus, but can't pinpoint it.

With regard to required pointing accuracy for the orbiter altimeter, Bryan has specified  $\pm 2$  degrees from vertical for his 9 degrees beamwidth. This was dictated by the requirement that the antenna gain be within the 1 db point.

With regard to altimeter hardware, there is an ongoing program. An altimeter will be flown on Skylab as a test bed, and Geos C will utilize an altimeter for geodesy and oceanographic measurements. G.E. Utica is the contractor for both. In Geos, NASA went with two contractors for a system study program: Teledyne-Ryan and GE Utica. GE Utica won the development contract. The Skylab flight model delivery is imminent.

With regard to a bistatic radar, Bryan has looked at this and thinks a bistatic mode is entirely feasible using either a ground-based transmitter or a space-based transmitter, but the reflectivity off normal incidence is not known. Bryan would encourage its use, however. He would prefer to put the transmitter on the spacecraft, and would want to tie the pulse system to the telemetry. A bistatic mode would need somewhat more power, but it might be possible to work into a 200-foot dish. There is no need to operate

the bistatic mode at the same time as the altimeter, but if operating from space, one can do both simultaneously. From a bistatic point of view it would be more interesting to keep the antenna pointed normal to the Venus surface and let the ground receive its signal at various scattering angles.

Bryan indicated that the radiometer would prefer a spinning mode, to utilize space as a cold load. Alternatively, with a separate cold sensing mode and heat pipe, one must decrease the gain of the regular antenna to match the cold load. Calibrations are needed about once a minute, or once every two or three minutes.

Regarding the radiometer science requirements, the tradeoffs are how close you can measure the temperature, as dictated by the system noise and the time you are allowed to integrate. We don't know the surface temperatures to more than 10 to 15 degrees. If we can get down to 2 to 5 degrees then this is fine. Bryan doesn't feel that we know enough now to perform meaningful tradeoffs for radiometer design. It would be desirable to have provisions to widen the bandwidth, or to switch in other IF filters and change the resolution of the radiometer. In a radiometer mode one can continue to make measurements out to an altitude at which the planet fills less than half the field of view.

Bryan feels that a Venus contour map will probably be like an Earth contour map, and one can't say that the southern hemisphere will be just like the northern. Global mapping is desired.

ALTIMETER AND RADIOMETER FOR A  
VENUS ORBITER MISSION

J. W. Bryan

K. R. Richter

December 1971

GODDARD SPACE FLIGHT CENTER  
Greenbelt, Maryland

ALTIMETER AND RADIOMETER FOR A  
VENUS ORBITER MISSION

J. W. Bryan

K. R. Richter

ABSTRACT

This paper presents the concept, constraints and capabilities of a radar altimeter type contour mapper for a Venus Orbiter Mission. The system was developed for the Goddard proposed Planetary Explorer Universal Bus concept. A system with a height precision of 30 meters over a surface area of 7200 square kilometers is achieved. Using this system and the orbit proposed in the orbiting "Bus" concept, the northern hemisphere of Venus is mapped in one Venus day. The radar receiver system, as conceived, is used in a radiometer mode to obtain a map of the diurnal and longitudinal variations of the Venus surface temperature with a resolution of 3.0 degrees Kelvin.

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## CONTENTS

	<u>Page</u>
ABSTRACT . . . . .	iii
INTRODUCTION . . . . .	1
PROPOSED ORBIT . . . . .	2
ANTENNA AND BEAM STEERING . . . . .	3
SYSTEMS CONCEPTS . . . . .	9
WEIGHT AND POWER . . . . .	11
RADAR DESIGN . . . . .	12
RADIOMETER MODE . . . . .	16
REFERENCES . . . . .	19

## ILLUSTRATIONS

<u>Figure</u>	<u>Page</u>
1 Venus Orbiter Configuration . . . . .	4
2 Venus Altimeter and Radiometer Coverage . . . . .	5
3 Altimeter Antenna Configuration . . . . .	8
4 Block Diagram . . . . .	10
5 Radiometer Cycle as a Function of Spacecraft Spin . . . . .	17

## TABLES

<u>Table</u>	<u>Page</u>
I Partially Despun Antenna Array . . . . .	7
II Weight and Power Estimates . . . . .	11
III System Characteristics . . . . .	15



## ALTIMETER AND RADIOMETER FOR A VENUS ORBITER MISSION

### INTRODUCTION

The purpose of this document is to present a plan at the conceptual level for the inclusion of a radar altimeter type terrain contour mapper for a Venus Orbiter Mission. A secondary purpose is to present a conceptual design of such a radar, to examine the constraints imposed upon the design by the proposed "Bus" concept (ref. 1) and to indicate trade-offs possible in the design of such an instrument.

Although Venus is our closest planet it is still somewhat of a mystery. The reason — perpetual cloud cover. Radar with its ability to penetrate clouds and map contours is one of the few instruments which can be used to study the topography of Venus. Earth based Radar studies by the Jet Propulsion Laboratory (refs. 2, 3,) have yielded much information about Venus such as spin rate, direction of rotation and orientation of the spin axis. During these observations some gross topographic features have been observed. However, due to the vast range, the instrumentation was unable to discern much in the way of surface features.

The proposed system will map the surface contours with a height resolution of 30 meters. The height is measured above a 7200 square kilometer area at the equator and less than 1000 square kilometer area at periapsis.

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## PROPOSED ORBIT

The proposed orbit for the orbital mission is a 24 hour, elliptical, polar orbit with a periapsis of 400km, and an apoapsis of 67,000km.

Periapsis will occur at  $45^\circ$  north latitude. During the proposed 24 hour orbit the planet will rotate approximate  $1.55^\circ$ . Considering this rotation and the planet radius (6040 km), the subsatellite point moves 164 km per pass at the equator and zero at the north pole. If the radar is active during each periapsis pass from the equator to the north pole, the northern hemisphere will be mapped in one Venus day (approximately 243 earth days). If an orbit reduction is then accomplished along with a  $180^\circ$  spin axis rotation the southern hemisphere can be plotted in similar fashion.

Assuming that a mean reflecting surface exists, a radar system can be designed to operate within the orbit mission constraints. The major constraints which have been considered are:

- a. The orbiter spin axis will always remain parallel to the planet spin axis.
- b. The orbiter spin rate will be 15 rpm
- c. Height above the planet at the planet equator is 1500km maximum.
- d. Height at periapsis ( $45^\circ$  N. Latitude) is 400km
- e. Subsattellite point velocity over the planet surface varies between 9.1 km/sec at  $45^\circ$  N. latitude and 7.95km/sec at the N. pole and equator.
- f. The angle between the normal to the planet surface at the subsattellite point and some external reference such as the sun, earth or stars, can

be defined to  $\pm 2.0$  degrees. This angle must be determined in a plane that is normal to the satellite orbit plane and contains the satellite and the subsatellite point.

- g. The angle between the normal to the planet surface and the spacecraft spin axis in the satellite orbit plane can be determined and programmed to an accuracy of  $\pm 2.0^\circ$ .

The basic function of this radar altimeter is to determine the height of the satellite above a mean surface at the subsatellite point. Due to the large illuminated surface area the height above any particular point on the surface is not measured. To establish a physical interpretation of the measurement, the height measurement is defined as the distance between the satellite and a mean of the spherical planet surface. The relation between this surface and the actual planet surface cannot be determined since the surface will consist of reflecting facets whose distribution is not known.

#### ANTENNA AND BEAM STEERING

An artist's concept of the Venus Orbiter showing the relative position of the altimeter antenna is shown in Figure 1. The contour mapping radar will supply a measurement of the vertical height of the spacecraft above the mean surface of the planet Venus. It will supply these measurements during each perigee pass as shown in Figure 2. The planar array antenna is conceived as being electronically despun during that portion of the satellite spin when the antenna bore site is within  $\pm 45^\circ$  of the subsatellite point. This despinning action

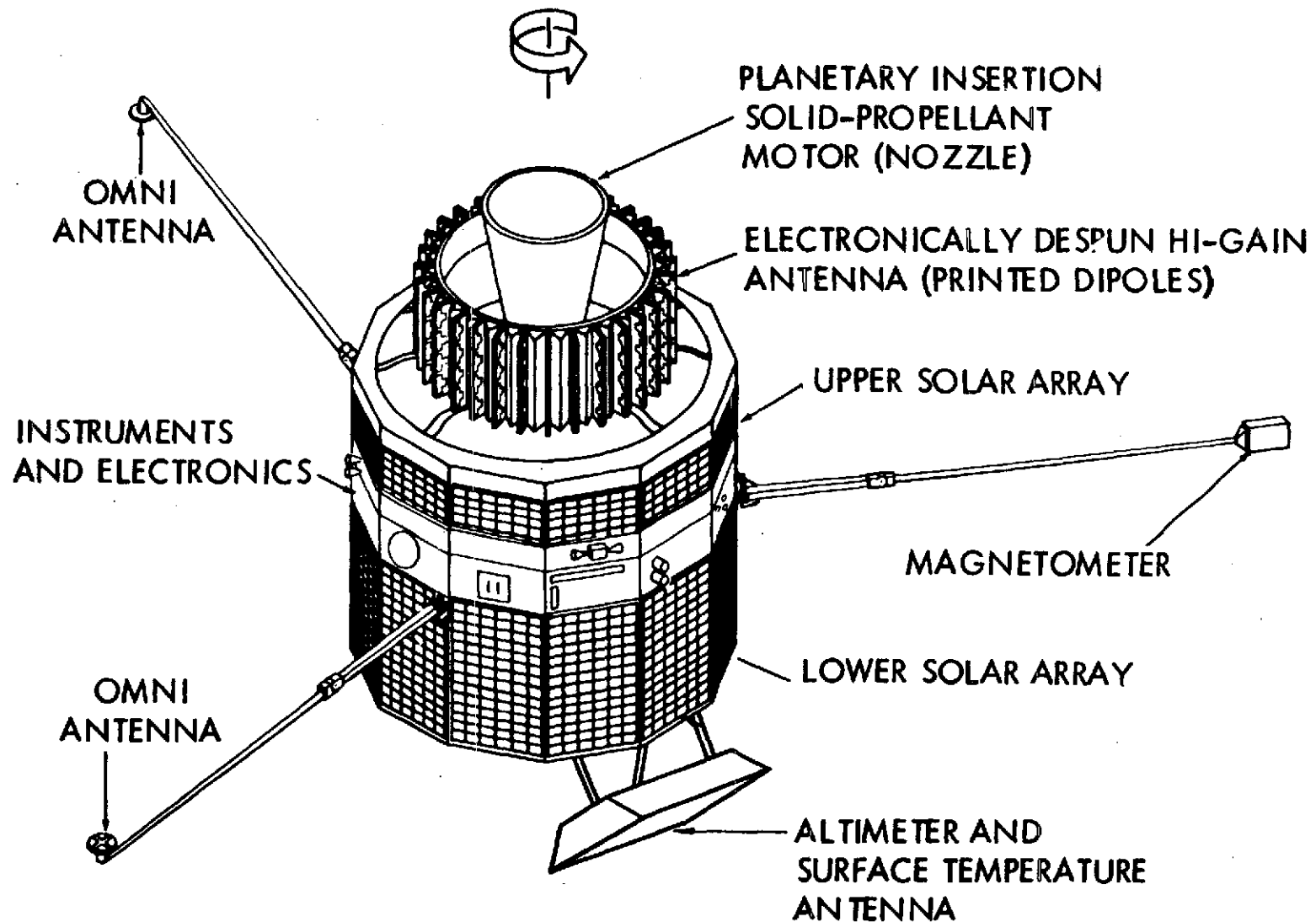


Figure 1. Venus Orbiter Configuration

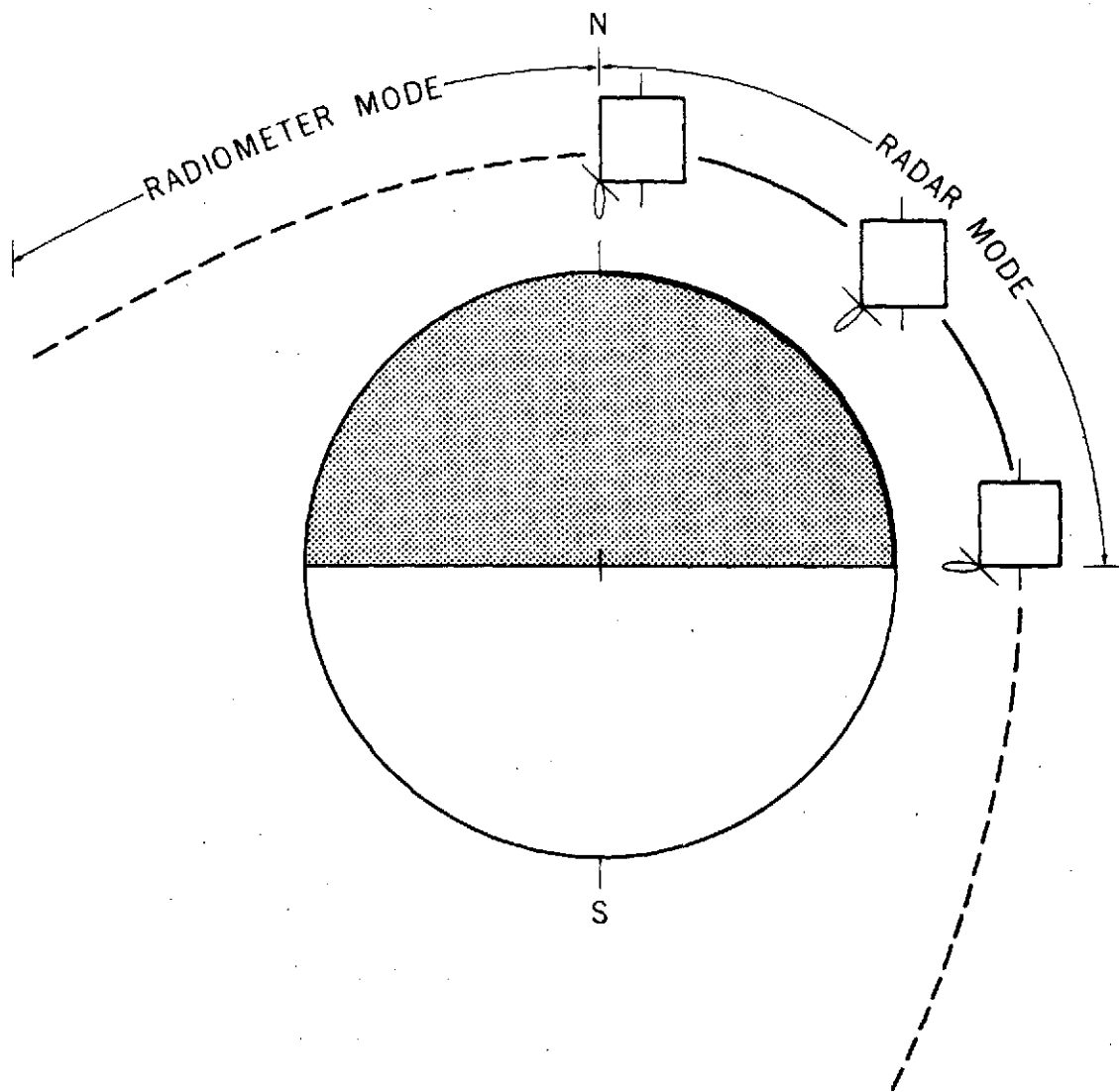


Figure 2. Venus Altimeter and Radiometer Coverage

coupled with an electronic beam steering maintains the radar beam pointing at the subsatellite point. The antenna is an 11 by 11 element phased array. This array is 75 by 75 by 15 centimeters with the back edges tapered to accommodate mounting and the spacecraft-launch vehicle adapter.

Phasing or beam steering will be in 0.25 degree steps. The steps will be synchronized with the spacecraft spin and orbit position relative to the planet such that each time the spin brings the antenna bore site within  $\pm 45^\circ$  of the subsatellite point the beam will have stepped  $0.25^\circ$  relative to the spin axis to keep the nadir point within the beam. This beam steering is necessary to keep the illuminating radar beam at normal incidence to the planet surface.

The  $0.25^\circ$  steps will require a 330 count stored in a countdown register. After passage over the north pole the register will count up the original 330. This count-up routine is not wasted and will be utilized in a radiometer mode.

The step size for equal sized steps is dictated by the velocity of the subsatellite point at periapsis. Since the array phasing elements must be designed for this step size, it is deemed cost effective to design all steps the same size. This results in overlapping of the illuminated area at the equator and pole. This overlapping can only help in constructing a vertical contour map of the planet.

Radar beam steering or despinning in the direction orthogonal to the orbit plane requires a reference that is not a portion of the spinning spacecraft. This is actually the electronic despinning function in relation to the spacecraft 15 rpm

spin. To maintain the radar beam pointing at nadir the concept is to constantly determine the angle formed by an external reference, the spacecraft and the center of the planet. The radar beam will then be maintained at this angle referred to the reference during the periapsis pass. This despun electronics will control the beam whenever the array bore site is within  $\pm 45^\circ$  of the subsatellite point. Since the radar beam is approximately 4.5 degrees between the one dB points, the beam pointing accuracy must be less than  $\pm 2.0$  degrees. This is within the state-of-the-art for either the reference sensor or scanning celestial attitude-determination system (SCADS). The 121 element phase array is illustrated in Figure 3 and the characteristics of this array are tabulated in Table I. The beam steering phasing elements are conceived as being housed behind the elements with control voltages being supplied from the spacecraft proper.

Table I

Partially Despun Antenna Array

Size	75 by 75 by 15 centimeters
Active Elements	121
Weight	6.8 kg
Gain ( $45^\circ$ off boresite)	25 dB
Steering Power (d.c.)	5 watts
Beam Width (3 dB)	9 degrees
Polarization	Circular
Feed Loss	2 dB

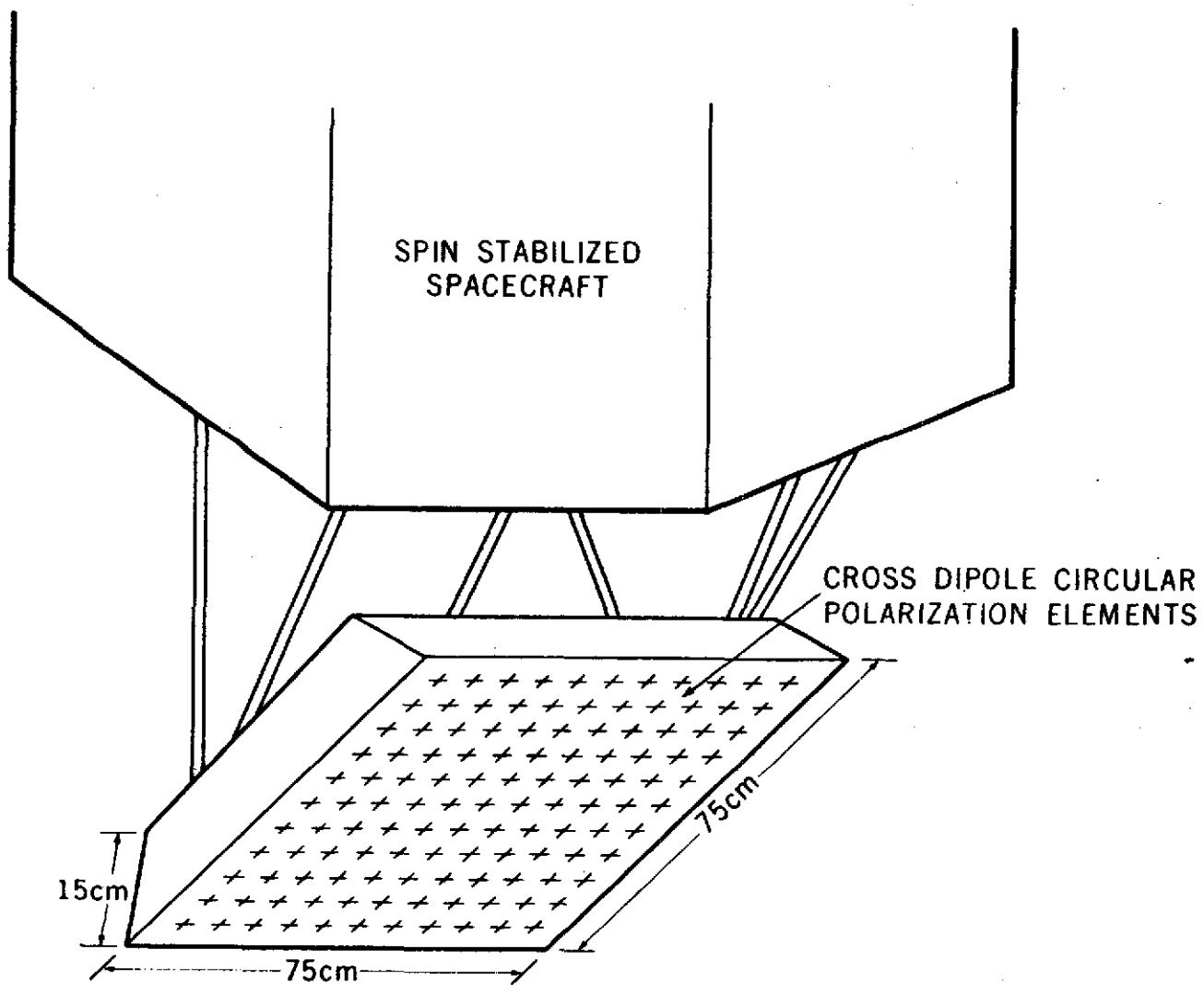


Figure 3. Altimeter Antenna Configuration



The d.c. power required to steer as well as despin the radar beam is estimated at 3.5 watts. This based upon the use of pin diode phase shifters. The countdown register is estimated to draw 0.5 watts d.c. during the active pass and during the count up in the radiometry mode.

## SYSTEMS CONCEPTS

A block diagram of the altimeter system is shown in Figure 4. All timing including the transmitter modulation frequency is synthesized from a common oscillator. A 10 kilowatt solid state transmitter generates the 10 cm wavelength pulses. Transmission and reception by the same antenna is accomplished via a duplexer. The superhetrodyne receiver has a 6dB noise figure and an IF bandwidth of 1.0 MHz. Data processing is limited to 1 second integration of the diode threshold detector output. The digitized altitude is shifted into the memory as a 16 bit word. To gain some information about the reflecting surface as well as the operation of the radar, the Automatic Gain Control (A.G.C.) voltage is included as a 5 bit word in the data storage. AGC is read at a one per second rate. The transmitter power is read and stored at a one per minute rate.

The total data storage required per perigee pass is 6400 bits. This information is transmitted to earth at a slow rate during the long swing out to apoapsis.

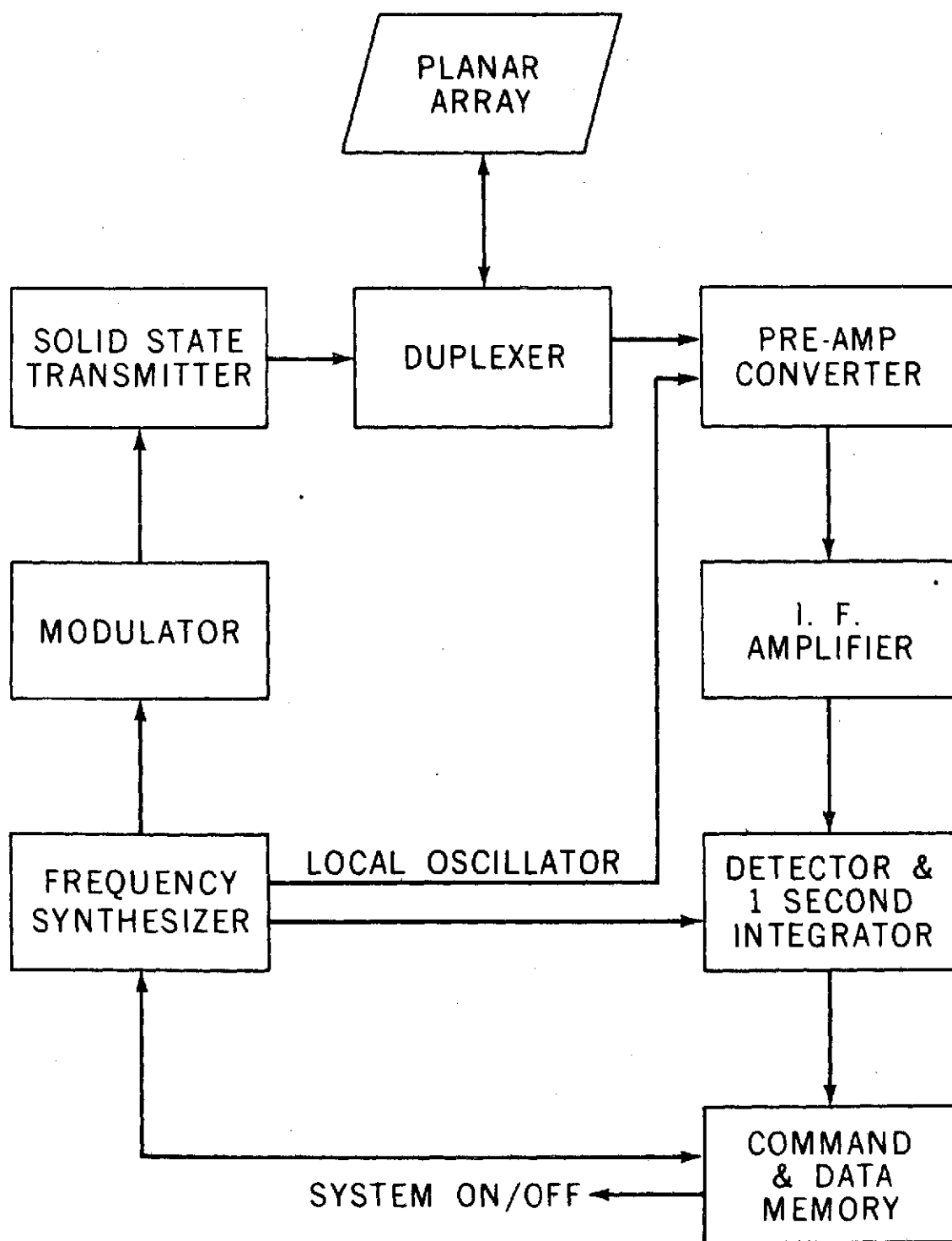


Figure 4. Block Diagram

## WEIGHT AND POWER

The weight and power estimates for the contour mapping radar are given in Table II.

Table II  
Weight and Power Estimates

Item	Weight	Power	Volume
Transmitter	4.99 kg	10 watts	500 cm <sup>3</sup>
Receiver	0.9 kg	5 watts	500 cm <sup>3</sup>
Antenna	5.9 kg	5 watts	0.084 m <sup>3</sup>
Memory	0.9 kg	1 watt	60 cm <sup>3</sup>
Hot Load	0.9 kg	1 milliwatt	40 cm <sup>3</sup>
Miscellaneous (cable etc.)	1.8 kg	NA	distributed
Totals	15.4 kg	21 watts	0.085 m <sup>3</sup>

These values are based upon the development of a solid state 10 kilowatt peak power transmitter and the continued development of microwave strip line subsystems. The inclusion of the radiometry mode increases the altimeter system weight by the 0.9 kilograms required for the hot load calibrator. Since the radar transmitter is off during radiometer measurements the total d.c. power is reduced by approximately 10 watts during temperature measurements.

## RADAR DESIGN

The per pulse signal to noise ratio is given by

$$S/N = \frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 H^4 K T \cdot B \cdot F_n \cdot F_{at}} \quad (1)$$

where

S/N	Signal to noise ratio
P <sub>t</sub>	Transmitter Power
G	Antenna Gain
λ	Wave Length
σ	Radar Cross Section
H	Range (Altitude above surface)
K	Boltzmann's constant
T	Receiver Temperature
B	Receiver Bandwidth
F <sub>n</sub>	Receiver Noise Figure
F <sub>at</sub>	Atmospheric Attenuation

The radar system considered is pulse width limited where the radar cross section is (ref. 4):

$$\sigma = \sigma^0 \pi c H \tau \quad (2)$$

where

σ <sup>0</sup>	Surface Reflectivity per Unit Area
c	Propagation Velocity
τ	Pulse Duration Time

Furthermore, the receiver bandwidth is chosen as the reciprocal value of the pulse duration time ( $\tau$ ).

Rewriting equation (1) one obtains:

$$S/N = \frac{P_t G^2 \lambda^2 \tau^2 c \sigma^\circ}{64 \pi^2 H^3 K T F_n F_{at}} \quad (3)$$

The first important decision which has to be made concerns the wavelength at which the radar should be operated. By inspection of equation (3) one sees that the signal to noise ratio depends on the wavelength only in terms of  $\frac{G^2 \lambda^2}{F_{at}}$ . The gain (G) and the effective area (A) of an antenna are related by

$$G = \frac{4\pi}{\lambda^2} A. \quad (4)$$

where A is proportional to the geometrical dimensions of the antenna. The physical size of the antenna is limited by the available space and spacecraft dynamics. The gain of a fixed aperture antenna may be increased by the use of shorter wavelengths.

For wavelengths in the cm-region, the attenuation in a neutral atmosphere increases with a factor  $\exp \frac{1}{\lambda^2}$  for decreasing wavelength (ref. 5). The two way attenuation through the entire atmosphere is given by

$$F_{at} = \exp (M/\lambda^2) \quad (5)$$

where M is a constant value which depends on the composition and on the total height of the atmosphere. Then the wavelength dependent term of the signal to noise ratio may be written as:

$$f(\lambda) = \left( \frac{4\pi}{\lambda} \right)^2 A \exp (-M/\lambda^2). \quad (6)$$

This function shows a maximum value at

$$\lambda = \sqrt{M} \quad (7)$$

Using the model for the atmosphere of Venus developed at Goddard Space Flight Center (ref. 6)  $M$  is calculated as 36.84 which yields an optimum wavelength of 6 cm (frequency ( $f$ ) = 5 GHz). However, the resulting value for the attenuation in the atmosphere may be low because no propagation experiment is available in the region of cm-wavelength in the lower atmosphere (ref. 7, 8). Therefore 3 GHz ( $\lambda = 10$  cm) has been selected as operating frequency.

In Table III the transmitter and receiver characteristics are given. These are required to obtain a per pulse signal to noise ratio of 5 dB for the worst case, (1500 km altitude). At the perigee of the orbit (altitude 400 km) the per pulse signal to noise ratio is increased by 17 dB. This value of 17 dB has to be considered as the minimum dynamic range of the receiver. An improvement of signal to noise ratio by approximately 10 dB is achieved by integrating 100 pulses (integration time = 1 sec).

The calculation of the signal to noise ratio is based on a reflectivity per unit area of  $\sigma^\circ = 0.08$  which is much lower than the reflectivity of 0.152 obtained by earth based radar measurements.

It must be pointed out that for the estimation of the signal to noise ratio rather pessimistic assumptions on the properties of the atmosphere and the surface reflectivity have been made providing a security margin for the mission.

Table III

System Characteristics

<b>Transmitter</b>	
Peak Power	10kw
Frequency	3 GHz
Pulse Length	1 $\mu$ sec
Pulse Repetition Frequency	100 Hz
Duty Cycle	$10^{-4}$
Average Radiated Power	1 W
D.C. Power	10 W
<b>Receiver</b>	
Noise Figure	6 dB
Bandwidth	1 MHz
Detection	Noncoherent
Threshold detector sensitivity	+5 dB
Integration time	1 sec
Clock Frequency	8 MHz
Sampling Gate	1 sec
D.C. Power	5 W

This radar provides a measure of the average altitude of the spacecraft above the planet surface.

The altitude error measurement due to the clock interval ( $\Delta t = 1.25 \cdot 10^{-7}$  sec) is:

$$\Delta R = \frac{c}{2} \Delta t \approx 19 \text{ meters} \quad (8)$$

The error due to the thermal noise in the receiver is smaller than 19m for the worst case ( $H = 1500\text{km}$ ). The total altitude error is less than 30 m from the equator to the north pole.

#### RADIOMETER MODE

The radiometer mode will be activated during that portion of the orbit covering the northern hemisphere of the planet as shown in Figure 2. The electronic despin which maintains the antenna beam in the orbit plane is disabled, the radar transmitter is commanded "OFF" and the radiometer hot load is activated as the spacecraft passes over the north pole. The electronic beam steering which maintains the antenna beam pointing normal to the planet surface is reverted to the "count up" mode as explained on page 6. The antenna beam will scan the surface at right angles to the orbit plane.

The r.f. noise temperature of the planet will be integrated over the one-fourth a spacecraft revolution as the antenna beam sweeps across the planet. At the spin rate of 15 rpm this results in an integration time of one second. The calibration temperatures will be recorded during those portions of the



spacecraft spin shown in Figure 5. Each integrated temperature will be digitized into a 9 bit word resulting in a quantization accuracy of less than 2.0°K.

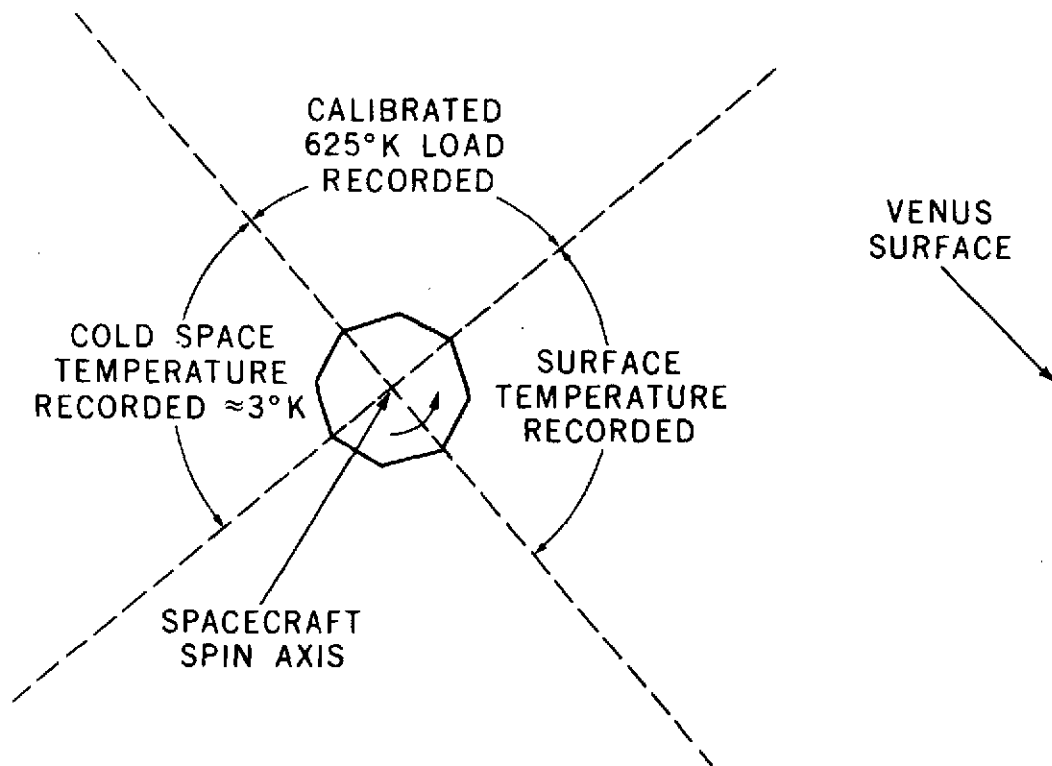


Figure 5. Radiometer Cycle as a Function of Spacecraft Spin

The radiometer temperature resolution is defined as:

$$\Delta T_{rms} = \frac{2 (T_s + T_p)}{\sqrt{B_n \times t_{int}}} \quad (9)$$

where

$T_s$  is the receiving system temperature (°K)

$T_p$  is the planet r.f. temperature (°K)

$B_n$  is the receiving system noise bandwidth (Hz)

$t_{int}$  is the measurement integration time (seconds)

For this radiometer system using equation 9

$$\Delta T_{rms} = \frac{2 (865 + 625)}{\sqrt{1.2 \times 10^6}} = 2.72^\circ K$$

where the expected planet temperature has been reduced by the 10 cm microwave attenuation of 0.8 dB through the planet atmosphere.

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3HES



## 5.3 INTERDEPARTMENTAL CORRESPONDENCE

TO: Distribution D      CC: NASA/ARC      DATE: November 14, 1972  
ORG: (thru S.Dorfman)      REF. HS507-0273

FROM: A.M. Lauletta/L.K.Acheson  
SUBJECT: Trip Report - Singer      ORG. 44-23  
Kearfott - 3 Nov. 1972

BLDG. 376      MAIL STA. 11141  
EXT. 8-4509/ 81086

On November 3, 1972 the writers visited Singer-Kearfott, study contractor for the wind-drift/altimeter radar for the large probe, at the request of NASA/ARC. This was the first such review held with a NASA/ARC study contractor which included both system study contractors. Those in attendance were:

<u>Name</u>	<u>Company</u>	<u>Title</u>
Barbara Pataro	Singer-Kearfott	Sr. Contract Administrator
Tony Lauletta	Hughes Aircraft	Experiment Integration Manager
Louis Acheson	Hughes Aircraft	Senior Scientist
Joel Sperans	NASA/ARC	Experiments Manager Pioneer Venus
Sid Russak	Martin	Experiments
Morris Sorkin	TRW	Staff Engineer
Gus Stavis	Singer-Kearfott	Department Manager
Lester Goldfisher	Singer-Kearfott	Member Technical Staff

The notes on the discussion in this meeting are attached. A general meeting including all participants was held first, separate meetings with Hughes/Singer-Kearfott and Martin (TRW)/Singer-Kearfott were held later.

A. M. Lauletta, Jr.

L. K. Acheson

Attachments: 1 - 9 pp.  
2 - 2 pp.  
3 - 3 pp.  
4 - 4 pp.

AML:LKA:vv

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A-159

## SINGER-KEARFOTT MEETING

GENERAL DISCUSSIONJoel Sperans (NASA Ames)

By way of introduction, as you know, the Science Steering Group selected a tentative payload for Pioneer Venus. The idea of a wind-drift radar was originally considered to be part of the primary payload, but the MIT Group made a counter suggestion to use DLBI. Shapiro made a good case for this at the first SSG meeting. At subsequent meetings he came back through Pettengill. There was still a lot of information missing at the time of the final report. The SSG decided to select DLBI as primary, with WDR as backup. DLBI, still unproven, was preferred under the assumption that on-board radar was a costly item. We countered this with the idea there might be a low cost radar approach, and SSG liked this, so two separate approaches were funded. For the initial selection of experiments it is likely that both will be chosen. We go into a two phase process. During the first phase more experiments will be selected than can be flown.

Since putting out the Wind-drift Radar RFP, we have gone to the low cost concept, and we are now asking what can be done with off-the-shelf hardware.

Les Goldfischer (Singer-Kearfott)

Our approach has been to work from the base of a commercial doppler radar for helicopters, the SKD 2100, which is a 4-beam device, and to utilize some components from a military radar, the AN/AP187. We are looking to a single beam device squinted off the vehicle and moving with the vehicle. Development of the antenna is the principal problem, because of the Venus environment. A ceramic filled waveguide with metallic cladding on the outside is being employed.

Tony Lauletta (Hughes)

What assumptions are you making about the environment?

Goldfischer

We are using the atmosphere contained in the Venus Baseline System Design Document (PV-1002.00A); the temperature and pressure plots on page 5-8, and the large probe descent profile on page 5-6.

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Sperans

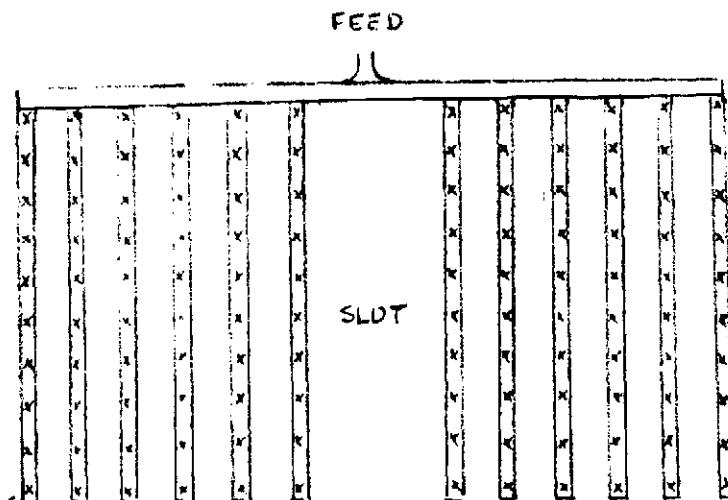
The original wind-drift radar specification is a model of what we would like to get, but we are not willing to pay money to get it.

Goldfischer

Our baseline design will get us up to a little over 30 km if we put in a transmitter capability of 0.5 watt (for the transmitting oscillator). Right now if we take the existing system we can only operate to 19 km (for both velocity and altitude data) and this requires 25 watts of power. To go up to 0.5 watt output (and 33 km) we need an additional 25 watts input from the probe.

The baseline operates at Ku band, 13.325 GHz. There would be an advantage in going to a lower frequency, e.g. 10 GHz, or even 8.8 GHz, but we haven't designed dielectrically loaded waveguides at these frequencies before.

The antenna configuration is as follows:



There is a slot in the center because our customer called for it.

We have only been working on this study for three weeks.

Operating at 13.325 GHz we have a  $5\frac{1}{2}$  degree beamwidth. If the requirement for a slot disappears we could make a  $10\frac{1}{2}$  x  $10\frac{1}{2}$  inch array.

Sperans

We were first thinking of burying the antenna in the insulation at the nose of the probe. The requirement for a slot came about because one experiment, the shock wave radiometer, had to look out at this point. But now we are carrying the radiometer in the heat shield, and so we don't need a hole. While some of the other instruments have a desire to look down, there is no specific requirement to look down from the center point.

Goldfischer

If we go to X-band, and keep the same beamwidth, we will need a  $12\frac{1}{2}$  x  $12\frac{1}{2}$  inch aperture. If we keep the same aperture we will lose a little gain, but we can afford to lose a little.

If we stick to a planar array we could go up the side just as well as on the bottom. We would much rather use a planar array than a curved array. If we did have to go to a curved array we would prefer to go to a cylindrical array.

Can a planar array on the bottom be worked out?

Lauletta

What is the thickness of the array?

Goldfischer

We can't give a thickness until we know the forces acting.

Sid Russak (Martin)

The force acting is simply the atmospheric pressure.

Goldfischer

We are concerned with wind stresses. If we make our antenna with a high dielectric ceramic, it could be as thin as a 1/8 inch wafer to satisfy the electrical requirements, but it will require structural strengthening. Pressure forces are not important, it is the wind forces. The principal wind will come from the vertical velocity.

Sperans

The scientific panel feels that the wind sheer is very low.

Goldfischer

We have been assuming that the spin axis points straight down. If the spin axis deviates from this by one degree, then in the absence of any wind velocity, we will get an indicated wind velocity of  $1\frac{1}{2}$  percent of the vertical velocity. The precision to which one needs to keep the spin axis is the precision to which you want to record the wind velocity.

We planned to squint the beam 10 degrees off axis, in order to not get too much scattering loss. This results in a 1.6 percent precision error. If one is talking about  $\pm 5$  degrees then the highest precision achievable is 10 percent of the vertical velocity.

Sperans

Is it possible to decipher the velocities from ground data?

Goldfischer

There is no way of separating the horizontal and vertical velocities. Even with a 4-beam system we are no better off. If we knew the surface was flat, we could get an indication of attitude from the return, but we don't know this.

Russak

Are you not looking at K band anymore?

Goldfischer

We are strongly favoring lower frequencies because of attenuation requirements. There is no longer any requirement for measuring clouds; there was no interest in the scientific community. Although our helicopter system operates at 13.325 GHz, fortunately we have done a lot of previous work on X band. We are using Duane Muhleman's curves on atmospheric attenuation as a function of frequency. (Muhleman is on the orbiter SSG.)

At one degree spin axis variation we are within spec, at a five degree variation we are way outside spec. We really need a vertical reference. If one could somehow set up a gyro system - but we don't know how to do this. You need an accelerometer reference.



Russak

You might measure the mean position of swing on the parachute.

Sperans

The project office has assumed a  $\pm 5$  degrees wobble as a no cost option. To get the one degree would take money.

Goldfischer

Regarding spin rate we don't have any problems, but we note an inconsistency between the specification of one sample/km in the RFP, and the baseline system design specification of 10 samples/km. We would use a different method of data processing for a slow spin rate than for a high spin rate.

Sperans

I know of no science requirement to get one reading every 100 meters, but one km sounds a little coarse. The original idea was to have a 10 rpm spin rate or less (Polaski).

Russak

Some other instruments want a higher spin rate, but it should be noted that it is not clear that a higher spin rate brings higher stability. You begin to get crossover effects.

Goldfischer

We would prefer a slower spin rate. The 40 bits per sample data requirement is based on transmitting all four beams simultaneously. We need 2 FM altimeter frequencies to avoid going into a hole in one of them, 2 velocity signals (assuming we want to separate velocity into vertical and horizontal components), and one time signal to tell where on the rotation the peak occurs (the latter is only meaningful if we have an azimuth reference, and the communications people say there may not be a null in the antenna pattern). With 8 bits per word, this comes out to 40 bits/sample. We would need a minimum of 4 samples/rev. to determine where the peak occurred.

Sperans

It came as a startling revelation to us that the communications people want a perfect antenna. They can't stand any degradation gain wise.

Russak

Are there significant differences in power, etc. if on board processing is required?

Goldfischer

There is a little addition, but it is not significant. It is all in the data processing package. We are estimating 15 pounds for the total weight with an overall volume of 3" x 8" x 8". The current helicopter radar takes up 700 in.<sup>3</sup>, but can be repackaged in a much smaller volume. Its weight is 15 pounds. The unit can be broken into smaller packages. The only piece which can't is the RF section, but the rest is card construction, and at an increased cost could spread out.

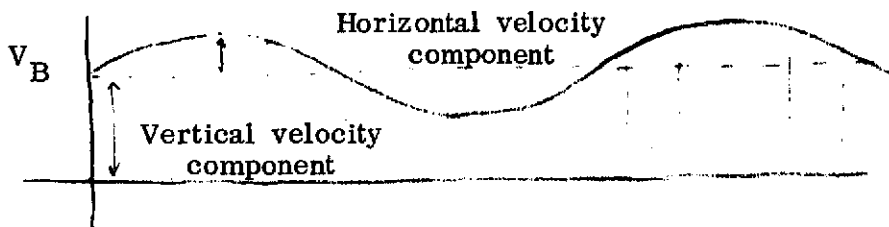
Joel, are you going to go back and resolve the sampling problem, i.e. how many samples/km are required?

Lauletta

We really need trade off studies.

Goldfischer

The velocity signal from the spinning beam looks like this:



The frequency tracker will be following this velocity continuously.

For ground data processing one needs to sample this waveform at least 2 times per cycle (theoretically) and practically 4 times per cycle in order to reconstruct it. If the data sampling period were very long then we would do on-board processing to determine the magnitude of the peak and the time it occurs. We will also have to transmit an azimuth reference.



Sperans

There will be an azimuth reference on board. Initially we will have a sun reference, but we will lose this at lower altitudes.

What you need, Les, is spin rate and sampling rate, and then you can decide on the data processing.

Goldfischer

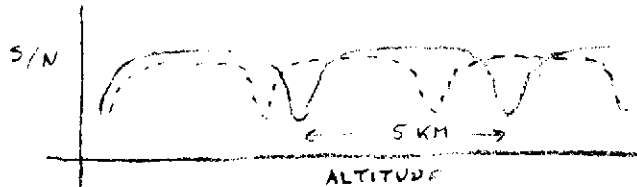
One might use the initial sun reference to set a gyro reference.

Sperans

There is also a problem on the small probes with an azimuth reference, which the magnetometer people want.

Goldfischer

Regarding the altitude hole referred to earlier, the FM frequency is in the vicinity of 30 khz, and there is an altitude hole every 5 km. If we were stuck with only one FM frequency, there would be a loss of doppler data at 5 km intervals, therefore one needs two frequencies to fill the gap, which could be a couple of thousand feet.



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Removal of the altitude ambiguity doesn't cost anything, it is just a data bandwidth problem. We are assuming that removal of ambiguities will be done on the ground.

Sperans

It is generally desirable to assume for the purposes of this study that both frequencies will be transmitted.

Goldfischer

We would like to operate as slow a tracker as possible, e.g. a one second time constant rather than 0.1 second. On that basis there is no purpose in taking samples more than one second apart. We could transmit samples once per second. This means 4 or 5 seconds/cycle or about 12 rpm. We wouldn't want the spin rate to be much faster than 10 rpm. We would have to go to a faster tracker, and operate at a higher S/N. For a  $\frac{1}{2}$  sec. time constant we need a 6 db S/N.

At 60 sec./rev. we could just as well send back everything, at 0.6 sec/rev. we have to design a new tracker; 10 to 12 rpm is optimum.

Sperans

You should determine the peak.

Goldfischer

We will provide the average peak velocity about every 20 seconds. We would sample at one/sec, hold two samples at all times and take differences, watching for a change of sign. We will take the difference between the peaks and average. If we transmit every 20 seconds then we have looked at 4 or 5 spins.

Sperans

If we assume one sample/km at high altitude, we will get more as the probe slows down.

Goldfischer

It will get as much as five times this.

I would like to hear the views of the probe study contractors on the desired location of the antenna.

Lauletta

Intuitively one would prefer a side antenna to a nose antenna because desired location of the antenna.

Russak

However, we would be very concerned if there were any lumpiness on the side. If one has to have a lump it is better to take it at the front.

Goldfischer

Regarding aperture size - on earth if you reduce the aperture by four then you reduce the altitude capability by two, but on Venus you pick up something from the reduced attenuation.

Sperans

There is a big argument on reflectivity. At the orbiter SSG, where we tried to talk people out of a radar altimeter, Pettengill thinks the power requirement will be far less than now assumed, but there is a 20 db uncertainty in attenuation and reflectivity.

Goldfischer

We have been using Evans Lincoln Lab paper as a reference, and the 1967 NASA handbook on Venus.

Sperans

We are thinking of turning on when the chute is dropped, at 45 km.

Goldfischer

If the sampling rate was one every 30 seconds we could shut down for 15 seconds to conserve power. An azimuth signal would be desirable so that synchronism could be maintained, e.g. be on for one spin and then off for one or two.

Sperans

Turning on and off of 25 watts doesn't sound attractive.

Goldfischer

If we go to the X band system we would like to be on at 55 km. At X band we get 55 km with 50 watts, and 25 km with 25 watts. At Ku band the corresponding numbers were 33 km and 19 km.

HUGHES ONLY DISCUSSION (MARTIN/TRW EXCLUDED)

During this discussion, at which both Goldfischer and Sperans were present, it was agreed to consider the following two baseline antenna configurations (see Figure, page 2).

- 1) A 10" x 10" planar array with  $\frac{1}{2}$ " thickness, assumed embedded in the insulation, located no farther than 45 degrees off the spin axis.
- 2) A cylindrical array with a 10" x 10" aperture, mounted with the radial elements oriented up and down, no farther than 45 degrees of the spin axis.

The ceramic antennas can stand a 500°C temperature. Weight is estimated to be a couple of pounds (density of ceramic is 150 lb/cu.ft).

A spin rate of 10 rpm or less is desirable but up to 15 rpm could still be tolerated.

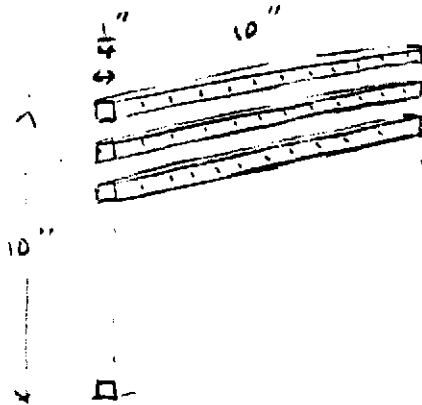
For the purposes of the baseline, consider that the radar will basically be a repackaged SKD 2100 plus a couple of cards from the AN/AP187 (the latter still considered proprietary by Singer). Data on the SKD 2100 is attached.

Fifty watts of unregulated power at 28 VDC will be required.

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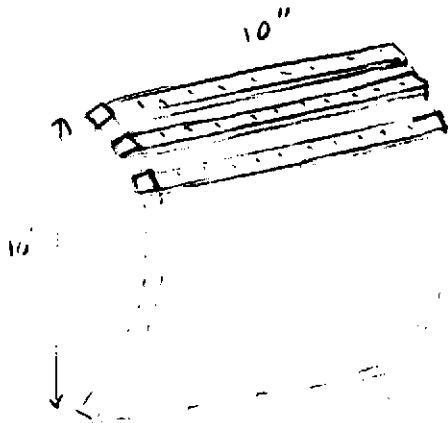
## BASELINE ANTENNA CONFIGURATIONS

### PLANAR ARRAY



( THE STRIPS MAY OR MAY NOT  
BE PLACED RIGHT UP AGAINST  
ONE ANOTHER. )

### CYLINDRICAL ARRAY



MOUNTED TANGENT TO SPHERE  
WITH ELEMENTS LINED UP ALONG  
SPIN AXIS ( FOR GOOD SIDELobe  
CONTROL TOWARD SPIN AXIS )

## 6.1 INTERDEPARTMENTAL CORRESPONDENCE

TO: Distribution D                      CC:                      DATE: 11 November 1972  
ORG:                                      REF. HS507/0267

SUBJECT: Trip Report - Orbiter                      FROM: LK Acheson/DM Newlands  
Radio Science Redefinition                      ORG. 44-24  
Meeting at ARC

BLDG. 376                      MAIL STA. 11141  
EXT. 84833/83814

Reference: ARC letter, Contract NAS 2-7250, "Advance Information Regarding Changes to the Pioneer Venus Orbiter RF Science Requirements," dated 2 November 1972.

The subject meeting was held at 10 AM on 9 November 1972. The purpose was to discuss the information in the referenced letter. Attending were:

<u>ARC</u>	<u>HAC</u>	<u>TRW</u>
Robert Christiansen	L. K. Acheson	H. A. Lassen
Terry L. Grant	J. N. Fisher	~ 4 others
John (Jack) Dyer	A. M. Lauletta	
	D. M. Newlands	
	C. D. Pedretti	

Bob Christiansen started the ARC presentation with a review of the genealogy of the orbiter radio science requirements. He then presented the new baseline radio science package. Both of these presentation charts are attached to this report. He indicated that although the study baseline is as shown on the chart, ARC did not rule out an integrated approach later on.

Terry Grant presented the assumed orbit parameters, the VOSSG used for the altimetry study. These were:

inclination;  $> 60^\circ$ ,  $90^\circ$  preferred  
periapsis; 200 km at  $45^\circ$  latitude  
period; 24 hours  
orbital velocity (periapsis); 10 km/sec  
spacecraft spin rate; 5 rpm

With this orbit, they estimate they get a  $90^\circ$  arc (16 minutes) within a 1000 km range. They intend to use the altimeter once each pass for one Venus rotation. He mentioned that the radio occultation experiment doesn't like a  $90^\circ$  inclination.



Grant discussed a report (attached to this memo) given by Dr. G. H. Pettengill to the VOSSG. The study baseline system mentioned above is system 2 in the matrix presented by Pettengill. It should be noted that the parameters presented by ARC in the referenced letter differ from those given by Pettengill in this analysis. However, the ARC numbers have been coordinated with Pettengill.

The pertinent altimeter parameters and their derivation are listed below:

<u>Radar System Parameters</u>		
<u>Parameter</u>	<u>Value</u>	<u>Derivation</u>
Frequency	2.3 GHz	Allows use of DSN if bistatic mode is added later on.
Equivalent Pulse Width	0.5 microsec.	TI design.
Pulse Compression Ratio	100	TI design utilizing acoustic delay lines to filter code.
PRF	150 Hz	Ability to utilize altitudes from periapsis to 1000 km.
Maximum Unambiguous Range	1200 km	
Number of Integrated Pulses	150	One second integration time S/N considerations
Doppler Shift	23 KHz	Nominal orbit. This is not severe for acoustic delay lines.
System Temperature	1450°K	4 dB NF receiver, 700°K due to surface of Venus.
Atmospheric Loss (2-way)	2.0 dB	Atmospheric model.
Surface Reflectivity	+13 dB	Pettengill (There appears to be some question as to just what this means.)
Amplitude Quantization	8 bits	Required accuracy.
Minimum Data Rate	5 bps (averaged per revolution)	One measurement per revolution
Maximum Data Rate	300 bps (averaged per revolution)	Profile of pulse return; 2 or 3 samples per revolution.

Mechanically Actuated Antenna

<u>Parameter</u>	<u>Value</u>	<u>Derivation</u>
Peak Power (RF)	13 dBw	Required for S/N.
Gain (30° azimuth (roll) x 14° elevation)	16 dBi	40% aperture efficiency
System Loss	2 dB	Estimate
Receiver Noise Figure	4 dB	Estimate
Polarization	Linear	No polarization sense change upon reflection.
System Weight	21 lbs.	Estimate
DC Power:		
Peak	110 w	30 w processor 80 w transmitter (25% effi- cient)
Per Revolution	16 w	Averaged over revolution
<u>NOTE:</u> There is no account for radar duty cycle during the "on" portion of the spacecraft spin period here.		
SNR at 1000 km	18 dB	Desired post-integration S/N

Electronically Phased Planar Array

<u>Parameter</u>	<u>Value</u>	<u>Derivation</u>
Peak Power (RF)	10 dBw	Required for S/N
Gain at 45° scan (max scan/min gain)	18 dBi	TI design
System Loss	1 dB	TI design (power modules close to radiators)
Receiver Noise Figure	4 dB	Estimate
Polarization	Linear	No polarization sense change upon reflection
System Weight	20 lbs.	Estimate based on TI design

Electronically Phased Planar Array (continued)

<u>Parameter</u>	<u>Value</u>	<u>Derivation</u>
DC Power:		
Peak	70 watts	30 w processor 40 w transmitter (25% efficient)
Per Revolution	12 w	Averaged over revolution

NOTE: There is no account for radar duty cycle during the "on" portion of the spacecraft spin period here. ARC stated that TI says the modules take same power whether transmitting or not.

SNR at 1000 km                      18 dB                      Desired post-integration S/N

The electronically phased planar array developed by TI consists of a 4 x 10 array with 10 amplifier modules each driving 4 radiators. A block diagram of the module is attached to this report. ARC says that for this application, the circulator shown must be replaced by a duplexer switch. Each module is a half wavelength on a side so as to fit closely behind the radiators. TI did not agree with Pettengill's reflection coefficient - they were much more conservative. However, in presenting the study baseline, ARC has adjusted the TI numbers to Pettengill's value for this coefficient.

ARC stated that TI initiated this work for Marshall for the Shuttle. ARC then asked them to investigate the use of this technique for the PV Orbiter HGA (i. e., an EDA). ARC was impressed and extended the study to include this altimeter electronically steered phased array. The message here is that ARC believes that TI has solved the EDA problem. ARC will forward a copy of the TI PV EDA study to us next month. TI is performing further studies on the radar altimeter design for ARC as shown in the attached chart.

ARC took the opportunity to present copies of the Stanford (Eshelman) report on propagation effects of the Venus atmosphere to both HAC and TRW.

Following the ARC presentation, there was a HAC question period (without TRW who had their turn in the afternoon). A transcript of this discussion follows:

Discussion Period (TRW excluded)

Present at the discussion were Bob Christiansen (Spacecraft Manager), Terry Grant (Communications) and Jack Dyer (Mission Analysis) in addition to the Hughes contingent.

Lauletta

Can we get a list of the members of the orbiter SSG?

Christiansen

Yes, I will try to get you a list later today.

Newlands

I am wondering why Ames now feels it necessary to separate the communications from the RF science, since we had been able to integrate the previous payload quite successfully.

Christiansen

The problem we have had is that the SSG thinking kind of got out of control. The Europeans had a concept of a giant despun, tilttable antenna which would have made this a radar satellite. The other science experimenters were concerned about the weight available for their instruments and so negotiated a 20-pound allotment for the RF science. This was a quick decision made without project concurrence or a detailed breakdown of the RF science. So we have been forcing things toward a definition.

The final decision to go to a dedicated altimeter instrument came from operational considerations. We weren't sure we really want to break communications for the radar. Also polarization was a problem. There are not a whole lot of things that can be shared when you come down to it. I hope you noticed that we might go back to an integrated design, but if we didn't early in the design make clear the differences between the two, it would be hard to have a basis for choice. Pettengill is a very persuasive guy.

Grant

It would be embarrassing to have a spacecraft design based upon an integrated system and then have it later not adopted.

Christiansen

Also, we didn't want to complicate the communication system design to accommodate something relatively unknown.

Newlands

Since we have a task statement for this, we will probably go ahead and document the integrated system studies already carried out.

In the new payload, do we have to consider both types of antenna, i. e., mechanical and phased array?

Christiansen

We are not prepared to say at the moment. This material was very quickly assembled. We want to look at what will eventually be easiest to integrate into the spacecraft.

Lauletta

We will probably have to consider both types.

Dyer

Can we say that both are of equal scientific value?

Christiansen

To first order the differences between them are that the planar array should present a less difficult integration problem, but may have more development problems, while the mechanical antenna may be easier to build but harder to integrate.

Newlands

Regarding data rate, I assume we should design for the higher rate, i.e., 300 bps.

Grant

Yes

Newlands

I believe the 13 dB surface reflectivity figure which Pettengill quotes (which TRW had questioned earlier) is a possible number, although quite high.

Grant

Pettengill is asking for a very high S/N also. He wants 20 dB.

Newlands

This tells us what kind of pointing one must assume. Obviously, one can't get much off vertical with 13 dB, i.e., one or two degrees.

Grant

Yes, one or two degrees.

Newlands

When you say S/N ratio, where do you mean?

Grant

After integration.

Grant

You are asking what sort of pointing accuracies we require, and I don't know what we can tell you.

Dyer

The pointing accuracy requirement is a function of antenna pattern.

Christiansen

It is not too critical, because you are transmitting in one direction and receiving in another as the spacecraft spins.

Grant

You want to know how this reflects into the spin axis pointing requirements. Because of the broad beamwidth, I feel that the pointing requirements of other experiments will be more stringent.

Newlands

What is the status of the microwave radiometer?

Christiansen

For the purpose of the study, it is gone. Very soon you will be receiving a payload update, based on the orbiter SSG recommendations, and you will learn more about this. The solar electron detector and the electric field detector will probably be gone also. I am sorry that this information is piecemeal, but we are not yet able to get into other areas than RF science since this involves internal decisions as to whether to accept the orbiter SSG recommendations.

Newlands

If the bistatic radar application goes down the tube, then it would be desirable for the radar frequency to not be at 2300 KHz to avoid interference with the communications system.

Christiansen

You would need to be offset in frequency sufficiently to avoid interference.

Newlands

Regarding terminology, the  $30^{\circ}$  antenna roll angle beamwidth is in azimuth I assume.

Grant

Yes, the antenna beam is short in elevation and long in azimuth.

Newlands

It is strange to see less system loss for the EDA than for the mechanical antenna.

Grant

This is what Texas Instruments is trying to show, that this can be possible if the modules are located right behind the antenna elements.

Newlands

Is the Texas Instrument's final report on the EDA out yet?

Christiansen

Yes. I don't have any more copies, but you can get a copy.\* Seeing some of the advantages of the TI approach to the EDA, we asked them to consider this for the radar altimeter. Later, it may be desirable to have a meeting with TI. We hoped to have the TI report on the PV EDA at the Kickoff Meeting, but it was delayed.

Newlands

In the letter we received, it is not clear about how the power is broken out. There doesn't appear to be a duty factor in there.

Grant

TI felt the DC power would not change if one were pulsing. So the DC power will be constant during the 1 second that the radar is on the planet. The transmitted power duty cycle does not enter here.

Fisher

I have some questions relating to spacecraft interface requirements. For the mechanically tiltable antenna, is it assumed that all the mechanisms required for this will come with the experiment?

\* NOTE: This is the Marshall report - not the PV ARC-funded EDA report which will be out next month.

Christiansen

Yes, there will be some sort of bolt-on fixture.

Lauletta

We would have to come up with some angular pointing requirements.

Christiansen

Yes, just like for any experiment.

Fisher

The radar needs to be turned on and off every spin cycle?

Grant

I think you would provide some synchronizing information to all experiments. You need some azimuth ticks.

Christiansen

As a first concept, we would initiate a programmed pointing sequence on command from the ground. We are not asking for a spacecraft sensor to tell where the planet is, we can calculate this.

Dyer

A number of experiments will need this information and this will vary over the orbit. Are you going to program all this from the ground?

Christiansen

We would have the same pointing program for each orbit, and if the spacecraft were properly injected into orbit, it could be done. TI will look at this.

Fisher

We are not going to have to provide a turn-on command every revolution, but will need a lot of pointing in between. In the 20-pound assumption, is it assumed you can do this with a stepper?

Grant

We feel we have to allow for quite a few commands, 10 or 12, which can allow the sequence to be established during apogee passage, and then have a timed command to start this sequence.



Newlands

Would you treat the roll program similarly?

Grant

Yes.

Fisher

Regarding the telemetry interface, the rate of 300 bps is an average rate, I take it. The peak is 3600 bps since the radar is on for 1 second out of 12. I assume you load the spacecraft memory during the 1 second period.

Christiansen

Should we discuss the probability of bit rate over the periapsis passage? For say 20 minutes, the radar can operate within 1000 km. At the longer ranges, the bit rate will be 5 bps because one will be making only altimetry measurements. We don't have a full periapsis period at 300 bps. For the purpose of a baseline, let us say that 50% of the time, we will be making pulse profile measurements at 300 bps.

Dyer

There are only 16 minutes below 1000 km.

Christiansen

What is the time below 400 km.

Dyer

The period below 400 km is about 8 minutes.

Christiansen

Tentatively, then, as a baseline, we will pick 50%.

Grant

Since we don't have any of the scientists here, we can pick any number we want.

Fisher

I want to ask again about the pointing accuracy of the spin axis.

Grant

It is reasonable to think that other instruments will dictate this.

Dyer

I believe that the IR radiometer is a narrow beam instrument, but if one is thinking of giving pointing information to the IR, it will be scanning past the limb and can tell itself where the planet is.

Lauletta

I don't know of any instruments that have a critical pointing requirement.

Grant

Then we better take this as an action item. Offhand, I would say on the order of a degree.

Dyer

I would say that also.

Grant

There are really two factors to consider - accuracy and stability.

Lauletta

Do we assume that the electronics is on the back of the antenna, or does it require space inside the vehicle?

Christiansen

It will require size and weight inside. In the next few days, we will be coming out with such a breakdown.

Fisher

With regard to coverage, you want to cover a hemisphere at under 1000 km.

Grant

Yes.

Christiansen

Hopefully, it won't be many days until the additional data on the orbiter payload is available.

The interface discussion can be summarized as follows:

1. The antenna (and mechanisms for mechanically steered antenna) will be part of the experiment (a bolt-on).
2. The electronics will be part of the experiment but will require equipment shelf space.
3. The experiment will require:
  - a) commands (prior to periapsis passage) to set the elevation pointing program and the roll transmitting program
  - b) spin index pulses
  - c) on/off commands (i. e., on at 1000 km prior to periapsis passage, off to 1000 km after periapsis)
  - d) power in accordance with the profile discussed previously.
4. Buffering will be done in the spacecraft. In the regions from 1000 to 400 km, the peak rate is 60 bps (5 bps buffered rate) and in the regions from 400 to 200 km, the peak rate is 3600 bps (300 bps buffered rate). The spacecraft is below 1000 km about 16 minutes and below 400 km about 8 minutes. Thus, the data rates divide equally with time. These numbers are based on the nominal radar orbit discussed previously.
5. No discussion was made of thermal control of the experiment, especially with regard to the distributed amplifiers on the electronically steered phased array.
6. The required experiment pointing requirements and resulting spin axis accuracy and stability will be defined later. Best estimates were 1 degree pointing accuracy.

Characteristics of the MVM X-band Radio Occultation Experiment are attached. This is the suggested form for the other candidate dual frequency occultation experiment.

LK Acheson  
LK Acheson

/nn

Attachments

DM Newlands  
DM Newlands

# ORBITER EXPERIMENT PAYLOAD - R-F SCIENCE REQUIREMENT

<u>DATE</u>		<u>SOURCE</u>		<u>R-F REQUIREMENTS DEFINITION</u>
• MAR '72	-	NASA RFP FOR PHASE B STUDY	-	INTERIM PAYLOAD DEFINITION <ul style="list-style-type: none"><li>• RADAR ALTIMETER IN GROWTH PAYLOAD</li><li>• S-BAND OCCULTATION ASSUMED</li></ul>
• JUN '72	-	PIONEER VENUS SSG REPORT (Orange Book)	-	"INTEGRATED" R-F SCIENCE PACKAGE <ul style="list-style-type: none"><li>• RADAR STRIP MAPPER</li><li>• DUAL FREQ. OCCULTATION</li><li>• BISTATIC RADAR</li></ul>
• OCT '72	-	ARC PAYLOAD DEFINITION REPORT VERSION I - DELTA VERSION II - ATLAS CENTAUR	-	EARLY VOSSG INPUTS <ul style="list-style-type: none"><li>• SIMPLIFIED RADAR ALTIMETER CONCEPT</li><li>• POSSIBLE SHARED USE OF TLM ANTENNA</li><li>• DUAL FREQ. OCCULTATION</li></ul>
• DEC '72 (Anticipated)	-	VENUS ORBITER SSG REPORT	-	VOSSG PAYLOAD RECOMMENDATIONS <ul style="list-style-type: none"><li>• DEDICATED RADAR ALTIMETER PACKAGE WITH CORRESPONDING WT. AND POWER BUDGET</li><li>• DUAL FREQ. OCCULTATION</li></ul>

A-185

## ORBITER R-F SCIENCE INTEGRATION GUIDELINES - PHASE B STUDY

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### • RADAR ALTIMETER

- NOMINAL PAYLOAD CATEGORY
- EXPERIMENT DEDICATED HARDWARE (DOESN'T SHARE TLM ANTENNA)
- BASELINE FUNCTION LIMITED TO PERIODIC S-BAND FREQ. SOUNDINGS ALONG SUB-ORBITAL TRACK NEAR PERIAPSIS.

### • S-BAND OCCULTATION

- NOMINAL PAYLOAD CATEGORY AS AFFORDED BY SPACECRAFT TELEMETRY
- ZERO WEIGHT AND POWER BUDGET

### • DUAL FREQUENCY OCCULTATION

#### • "OTHER CANDIDATE" CATEGORY

- X-BAND MYM '73 HARDWARE
- USE OF TELEMETRY ANTENNA
- OTHER X-BAND HARDWARE
- DEDICATED X-BAND ANTENNA

BASELINE APPROACH FOR  
SYSTEM STUDY

ALTERNATIVES UNDER  
ARC INVESTIGATION

Matrix of Radar Possibilities

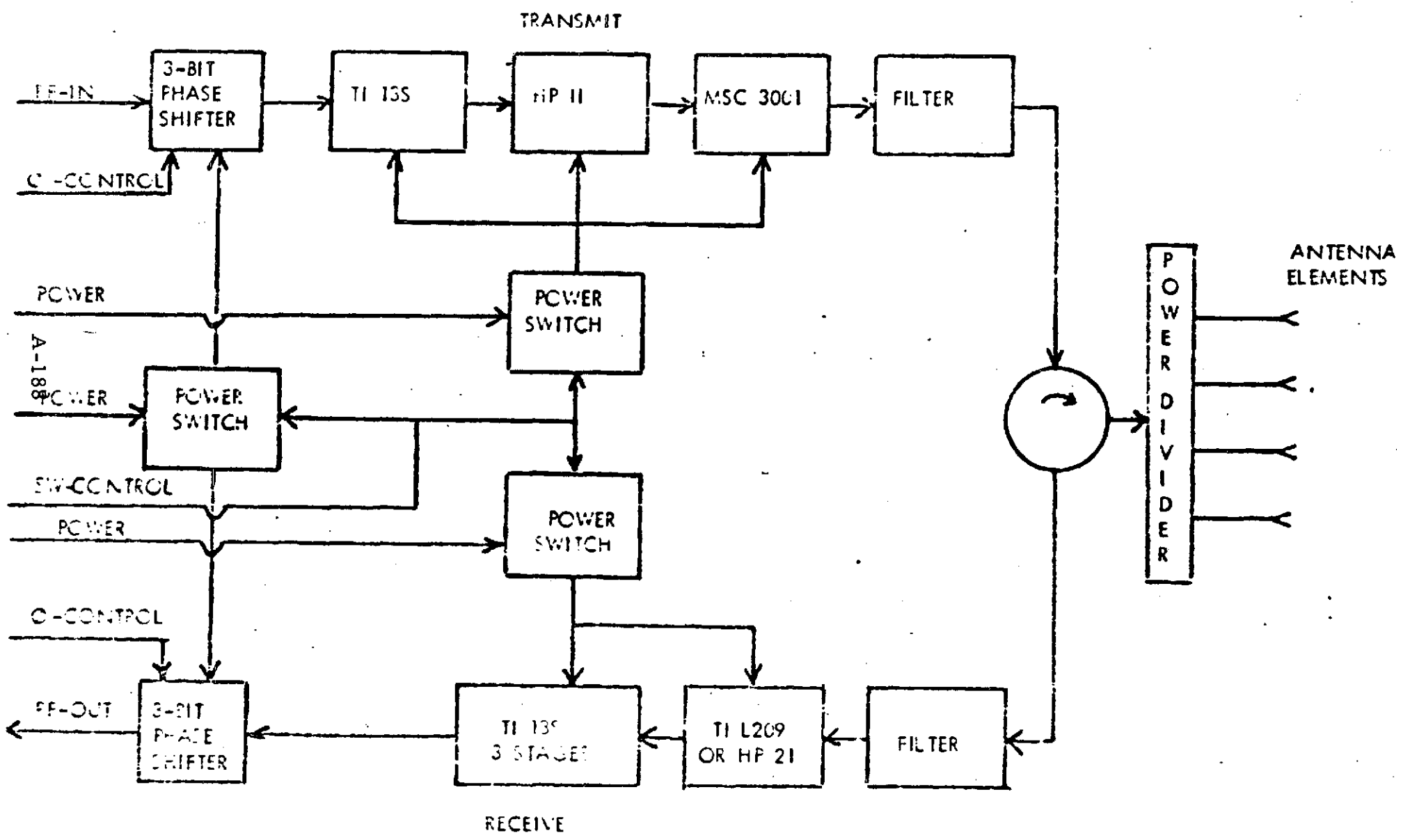
- Assuming:
- 1) High-resolution, S-band altimeter only; antenna not despun and not tiltable, single linear polarization;
  - 2) System (1) but with tiltable antenna;
  - 3) System (2) but with concentric X-band system;
  - 4) System (2) but with dual polarization (preferably circular)
  - 5) System (2) but fully despun

Surface Measurement Objectives*	<u>Radar System</u>				
	(1) (elemental)	(2) (tiltable)	(3) (X-band)	(4) (dual pol'n)	(5) (despun)
I. Topography	Sporadic	Grid	Grid	Grid	Strips
II. Features	Sporadic	Grid	Grid	Grid	Strips
III. Geopotential	None	None	Grid	None	None
V. Dielectric Const.	V. Poor	Poor	Poor	Good**	Fair
V. Meter-slopes	V. Poor	Poor	Poor	Good**	Fair
I. Cm-roughness	None	None	None	Good	None

\*Note: For any of the radar systems considered here, it is possible to make the measurements listed below only for regions of the surface lying within approximately plus and minus 45° along the orbital trace from periaapse. Assuming an operational lifetime of one Venus rotational period (243 days), this will give a limit to the total coverage of about one-half of the planet, with the maximum latitude set by the choice of orbital inclination. The quality of the coverage within this allowed region is rated in the table. Because of earth-Venus geometry, a comparable limitation applies to bistatic measurements.

\*\*The rating of "good" here assumes bistatic measurements.

# TRANSMIT / RECEIVE MODULE



## FURTHER RADAR DESIGN EFFORT

### REFINE S-BAND SYSTEM DESIGN

- OPTIMIZE ELECTRONIC ARRAY
- CONSIDER DESIGNS FOR TILTING THE MECHANICAL ANTENNA
- DETAIL THE PROCESSING CIRCUIT DESIGN
- CONSIDER DIGITAL FILTERING FOR HIGH PULSE COMPRESSION RATIOS
- DETAIL A PROGRAMMER DESIGN FOR ANTENNA LOOK ANGLE AND ROLL ANGLE
- REFINE WEIGHT AND POWER ESTIMATES

### ALTERNATE DESIGNS

- CONSIDER ADDED REQUIREMENTS FOR CIRCULAR POLARIZATION
- CONSIDER ADDED REQUIREMENTS FOR ADDING X-BAND RADAR
- CONSIDER A DESIGN FOR INTEGRATING THE ELECTRONIC ARRAY WITH AN EDA



DRAFT

Some Considerations Affecting Orbital Radar Altimetry  
of the Planet Venus

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Cambridge, Massachusetts 02139

Prepared for the Joint NASA/ESRO Working Group  
Pioneer/Venus Orbiter Mission

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# I. Objectives of Venus Orbital Altimetry

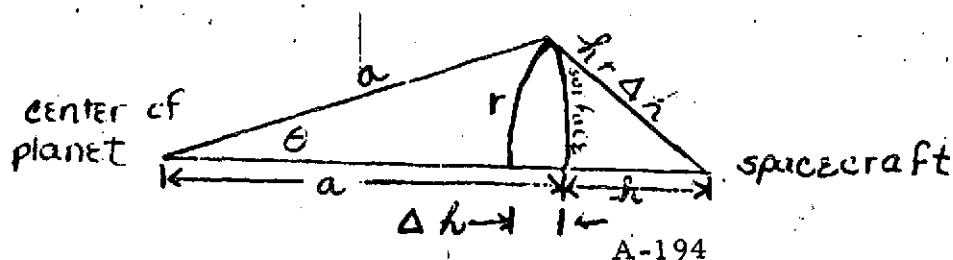
The primary objective of a radar altimeter in orbit around Venus is, loosely stated, to measure the precise distance between the orbiter and the nearest point on the surface below. Secondary objectives include finding the reflectivity of the surface at normal incidence, the degree and type of surface roughness (using both the quasi-specular and diffuse scattered components), and the amount of atmospheric attenuation lying in the vertical path (using two or more separate radar systems with wavelengths appropriately selected to distinguish propagation from surface scattering effects). The use of the term altimeter here serves to emphasize its height measurement role as distinct, for example, from an imager whose primary function is to map the scattering at radio wavelengths of a large portion of the planetary surface. In general, the latter role requires a more complex (and, therefore, heavier and more expensive) payload than the former, but the distinction is not exact. In the present case, for example, it is expected that the proposed altimeter will yield a map of the surface scattering and topography of a considerable portion of the planet Venus after a period of some 243 days (one planetary rotation).

In what ways will these measurements be useful to planetology? Since the orbit of the spacecraft can be established with good precision from earth-based tracking, the height measurements (hopefully to an accuracy of 15 meters, or so) may be converted immediately into a map of absolute surface height along the sub-orbital trace. From this the geometric planetary oblateness

may be directly calculated, yielding possible information on past spin rates. The topography and radar scattering characteristics (with a lateral resolution of 10 km or better) of features may permit inferences concerning mountain-building, volcanic activity, erosive processes, and the absence (presence?) of liquid oceans. If scattering measurements at two different wavelengths are available, with one of the wavelengths chosen sufficiently short (say 3 to 4 cm) to interact strongly with the thick atmosphere of Venus, it is possible to compare actual surface heights with pressure heights and, from these, to calculate the height of geopotential contours with useful accuracy (see Shapiro et al, 1972). From these, in turn, it is possible to calculate the degree to which the surface is isostatically compensated, and to infer mechanical properties of the planetary interior. Such information, of higher resolution than obtainable from the spacecraft orbit, also allow calculation of planetary gravitational anomalies which are of especial interest in view of the apparent lock between the rotation of Venus and the orbit of earth.

## II. Radar Performance and Resolution

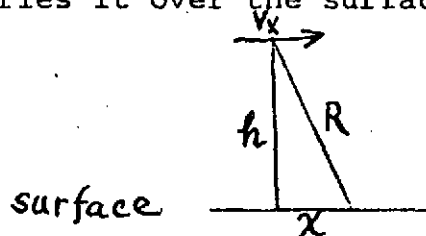
Assume a spacecraft at an altitude  $h$  above a spherical planet of radius  $a$ , and having a radar with delay resolution  $\tau$  (range resolution  $\Delta h = c\tau/2$ ). The cap constituting the nearest portion of the planet lying between  $h$  and  $h + \Delta h$  will then be defined as



$$\begin{aligned}
 (h + \Delta h)^2 &= a^2 + (a + h)^2 - 2a(a + h)\cos\theta \\
 h^2 + 2h\Delta h + (\Delta h)^2 &= h^2 + 2a(a + h)(1 - \cos\theta) \\
 h\Delta h/a(a + h) &= 1 - \cos\theta \approx \theta^2/2, \text{ for } \theta \ll \pi/2 \\
 r \approx a\theta &\approx [2ah\Delta h/(a + h)]^{1/2} \quad (1)
 \end{aligned}$$

$$\text{Area of cap} \approx \pi r^2 \approx 2\pi ah\Delta h/(a + h) \quad (2)$$

If the radar system is of the coherent type, it is possible to analyze the power returned as a function of doppler frequency, i.e. according to the relative phase of successive echoes. In this way the contributions of certain regions lying within the resolved cap can be distinguished as the velocity of the spacecraft carries it over the surface. The geometry is given by:



If  $x \ll h$ ,

$$\Delta f = 2\dot{R}/\lambda = 2xv_x/\lambda h \quad (3)$$

where  $v_x$  is the component of the spacecraft's velocity parallel to the surface,  $\Delta f$  is the doppler shift, and  $\lambda$  is the radar wavelength. Thus, if sufficiently narrow frequency filtering is available, the contribution of small strips perpendicular to the trace of the orbital path may be resolved. In particular, further resolution may be obtained within the cap area previously defined in delay. It is assumed, of course, that the vertical component of the spacecraft's velocity,  $v_y$ , can be calculated from the known orbital parameters, and allowed for in the processing.

In general, the surface will not be completely smooth to a fraction of the radar wavelength over the area of the resolved cap. A convenient representation of the statistical surface

scattering of radar waves has been found to be given by a law of the following type (Magfors, 1964)

$$\sigma(\theta) = (\rho_0 C/2) (\cos^4 \theta + C \sin^2 \theta)^{-3/2} \quad (4)$$

where  $\sigma(\theta)$  is the specific radar cross section (i.e. per unit surface area) at angle of incidence  $\theta$  with respect to the mean surface vertical. The parameter  $\rho_0$  is the reflectivity at normal incidence to a flat surface (square of the Fresnel coefficient) and is related to the surface electrical characteristics in a theoretically known way. The parameter  $C$  characterizes the waveness of the surface and can be related to the average surface slopes under certain conditions.

Moving now to a calculation of the anticipated echo signal strength, we may write the radar equation as

$$P_r = P_t G^2 \lambda^2 \alpha \sigma / (4\pi)^3 h^4 \quad (5)$$

where  $P_r$  and  $P_t$  are the received and transmitted powers, respectively,  $G$  is the antenna gain in the direction of observation,  $\alpha$  is the 2-way propagation loss in the planetary atmosphere, and  $\sigma$  is the radar cross section of the resolved surface area. Equations (2), (4) and (5) may be combined to give

$$P_r = P_t G^2 \lambda^2 \alpha \rho_0 C a \Delta h / 64 \pi^2 h^3 (a + h) \quad (6)$$

If the frequency resolution is sufficient to define a scattering region, as given in eq. (3), which is smaller than the cap defined by the delay resolution, the returned signal will be proportionally less. Note that  $\theta$  has been taken as zero in this special case of vertical sounding.

To get the signal-to-noise (SNR) ratio, we need, finally, the r.m.s. fluctuation of the detected noise in the receiver

$$[\overline{P_N^2}]^{1/2} - \overline{P_N} = kT/\tau(N)^{1/2} \quad (7)$$

where T is the total receiving system noise temperature when looking at the planet. Equation (7) assumes incoherent detection using a filter matched to the delay resolution, with N measurements summed after detection. Coherent detection, as long as it does not reduce the effective radar cross section of the surface, (and assuming that propagation through the thick atmosphere of Venus does not introduce significant phase noise) will further reduce the noise competing with the signal.

The ratio of eq. (6) to (7) yields the signal-to-noise ratio for an incoherent radar. In a practical spacecraft system with solid-state components, a phase-coded modulation will almost certainly be used to obviate the need for high peak powers. For a code of length M and an output device power limitation, P, we have an effective peak transmitted power of MP. The actual power drawn from the spacecraft's power supply will be less than P by the duty factor which results from two causes: 1) The need to turn the transmitter off to listen for echoes, and 2) if an antenna fixed to the spinning spacecraft is used, the desire to turn the transmitter off when the antenna is not correctly pointed.

### III. Sample Calculation

To gain a feeling for the requirements of spacecraft altimetry, it is useful to calculate the SNR expected under some reasonable assumptions for a radar configuration. Observations of the equatorial region of Venus which have been made from earth can be used to estimate the surface scattering characteristics. We assume

an incoherent radar, and shall insist that a reliable detection be made in about 1 sec of observation. This limit is set by the spin of the spacecraft (period of about 10 seconds) and by the desire that the spacecraft's track on the surface during the observation not exceed the resolution set by the radar's delay resolution. At 10 km/sec orbital velocity, the distance covered is about 10 km, and we see from eq. (1) that at a height of 400 km the corresponding delay resolution needed is 1  $\mu$ sec. A reasonable set of assumptions for the radar parameters is given in Table I.

Table I.

$P = 25 \text{ w}$ ( $P_{DC} < 5\text{w}$ )	$a = 6.1 \times 10^6 \text{ m}$
$M = \text{code length} = 1023$	$h = 4.0 \times 10^5 \text{ m}$
$P_t = MP = 2.5 \times 10^4 \text{ w}$	$\tau = 1 \times 10^{-6} \text{ s}$
$G = 32$ (15db)	$\Delta h = c\tau/2 = 150 \text{ m}$
$\lambda = 0.15 \text{ m}$ (2000 MHz)	$T = 1.5 \times 10^3 \text{ }^\circ\text{K}$
$\alpha = 0.6$ (-2db)	PRF = pulse repetition frequency
$\rho_o = 0.15$	$= 10^2 \text{ sec}^{-1}$
$C = 150$ } typically observed from earth	$N = 30$
Observing Time = 0.3 sec	

We note that there is an intrinsic frequency filtering with a half-power bandwidth of about 1 kHz arising from the decoding of the phase modulation over the interval  $M\tau$  ( $= 1023\mu\text{s}$ , here). From eq. (3) we find that  $\chi = 3 \text{ km}$  for  $h = 400$ , and that the resolved surface area contributing to the observed radar cross section is, therefore, 0.3 times the value given in eq. (6).

Making this correction (which also requires that the incoherent integration time be reduced to 0.3 sec in order to preserve the 3-km surface resolution) and inserting the parameters of Table I into eqs. (6) and (7), we find  $SNR = 2100$ . Note that a pulse repetition frequency of 100 per second has been chosen, allowing up to 1500 km unambiguous range. At the same time, the length of an individual transmission,  $M$ , is only  $10^{-3}$  sec, allowing operation down to heights of about 150 km. For SNR's in excess of 100, one can conservatively expect a ranging accuracy of better than 15 m; how much better depends on systematic error and the homogeneity of the resolved surface. Note that the SNR depends approximately on the cube of the height in the domain  $h \ll a$  (see eq. 6; in the present example there is even less reduction in the SNR with height because of the effects of  $\Delta f$  on cross section and  $N$ ). Therefore, measurements can be made in most cases to heights of 1500 km. The worst expected case of an "uncooperative", i.e. rough, surface would lower the signal strength by a factor of 100, based on measurements from earth.

Incorporating a coherent detection system would be of little benefit in the proposed system, unless imaging were to be undertaken. The impact of this on the data rate would be considerable. The SNR's calculated here indicate that it would be possible to study the cross-polarized echo (which would be about 1000 times weaker than the quasi-specular echo assumed above) at heights below 400 km.

The calculation for an X-band radar system is similar to the above except for possible changes in  $G$  (higher?),  $P$  (lower?),



$\lambda$  and  $\alpha$ . The net effect would probably be to reduce the SNR, but if the product  $G^2P$  were held constant for a system at  $\lambda = 4$  cm, the net reduction would be a factor of about 100-- still tolerable for measurements below 500 km.

The required information storage for the minimum system (one polarization, no X-band) may be roughly estimated from the need to record about 500 6-bit intensity samples plus perhaps 50 more bits of tracking and gain loop information per 10-second spacecraft rotation, to yield an average of about 300 bits per second during a periapse passage. Adding X-band and cross polarization S-band receivers would probably add an additional 50 to 100 bits per second. Up-link commands might be required to aid in initial acquisition, but these could be accomplished well in advance of the periapse passage. Adding coherent processing would likely at least triple the basic data rate, but would be applied only to the quasi-specular S-band receiver.

The systems described above can be constructed using digital processing techniques which are well understood and for which current integrated circuit technology is well suited. They place tolerable demands on available spacecraft weight, power and information storage and transmission capacity. In short, it is felt that the cost of adding radar altimetry capability to an orbiter mission is in reasonable proportion to the expected scientific output.

#### REFERENCES

Shapiro, I.I., "Wind-speeds in the Lower Atmosphere of Venus: Status Report on Possible Measurement via Differential VLBI Tracking of Entry Probes." Report to Pioneer/Venus SSG, June, 1972.

Hagfors, T., "Backscattering from an Undulating Surface with Applications to Radar Returns from the Moon. J. Geophys. Res. 69, 3779 (1964).

**CHARACTERISTICS OF THE MVM**

**X-BAND EXPERIMENT**

- . Transmitted Signal - Carrier Plus Turn-Around Ranging
- . Simultaneous and Coherent with S-Band Transmission
- . Antenna - High Gain Dish Via a Dual Frequency Feed
- . R.F. Power Output - 250 Milliwatts
- . D.C. Power Required - 10 Watts
- . Added Weight - 5 + lbs. (2.27 + Kg)

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TO: Distribution D  
ORG:

CC:

DATE: November 13, 1972  
REF: HS507-0269

SUBJECT: Ames Visit on  
9 November 1972

FROM: A. M. Lauletta, Jr.  
ORG: 44-23

BLDG. 376 MAIL STA. 11141  
EXT. 8-2479

An RF Science meeting was held at Ames on 9 November 1972; which Acheson and Newlands will report on, after which an informal meeting was held with Lou Polaski to discuss the cloud particle sensor and solar radiometer.

Lou indicates they are preparing detailed experiment interface requirements which will be available in two to three weeks, this was also referred to in the RF Science meeting, i.e. the Orbiter altimeter.

The cloud particle analyzer in the large probe has changed significantly as shown in the sketch. The device now consists of a 10-inch long by 5-inch diameter cylinder, housing all electronics and the light source (laser) which must be attached to the inside of the pressure vessel looking out through the vessel wall. On the outside a bridge structure is attached to provide support for the mirror. This external structure will probably extend about 6 inches from the external surface of the pressure vessel. The base supports of the bridge structure are about 3 inches apart. The bridge plane must be oriented perpendicular to the spin axis. There are two possible window configurations required in the pressure vessel between the internal light source, light receivers and the external mirror. The first is a one inch diameter window located at the center between the two support posts. The second requires two windows,  $\frac{1}{2}$  inch and  $\frac{1}{2}$  inch in diameter on a line between the two support posts. Until better defined, I suggest we use the one inch diameter window. No information was available on window requirements, it may be a GFE item as part of the experiment. Alignment and stability between the mirror and internal optics is critical and is being evaluated. The bridge structure and mirror should be considered part of the experiment supplied to Hughes. Some additional characteristics are:

- Weight - 8 pounds
- Power - 40 watts (20 watts regulated and 20 watts unregulated)
- Data Requirements - 256 bits/sample, 5 samples/kilometer (same as before).
- Volume - 205 in<sup>3</sup> (internal volume, prefers warm location)


On the shock layer radiometer I asked Lou if it could be mounted up along the skirt rather than the stagnation point. After calling Ellis Whiting (ARC), he indicated that their analysis had been done at the stagnation point which was based on spherical flow, this was important to interpreting the data. The revised flow conditions and perturbations to it, possibly from unstable aerodynamic conditions, would require different analytical procedures of which they were unfamiliar. However it did not appear to be impossible just much more difficult and perhaps unfamiliar territory for the experimentalists, as I interpreted it.

A-205

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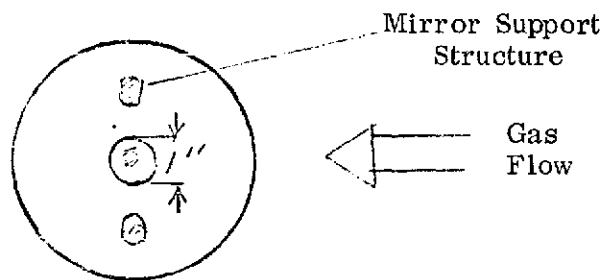
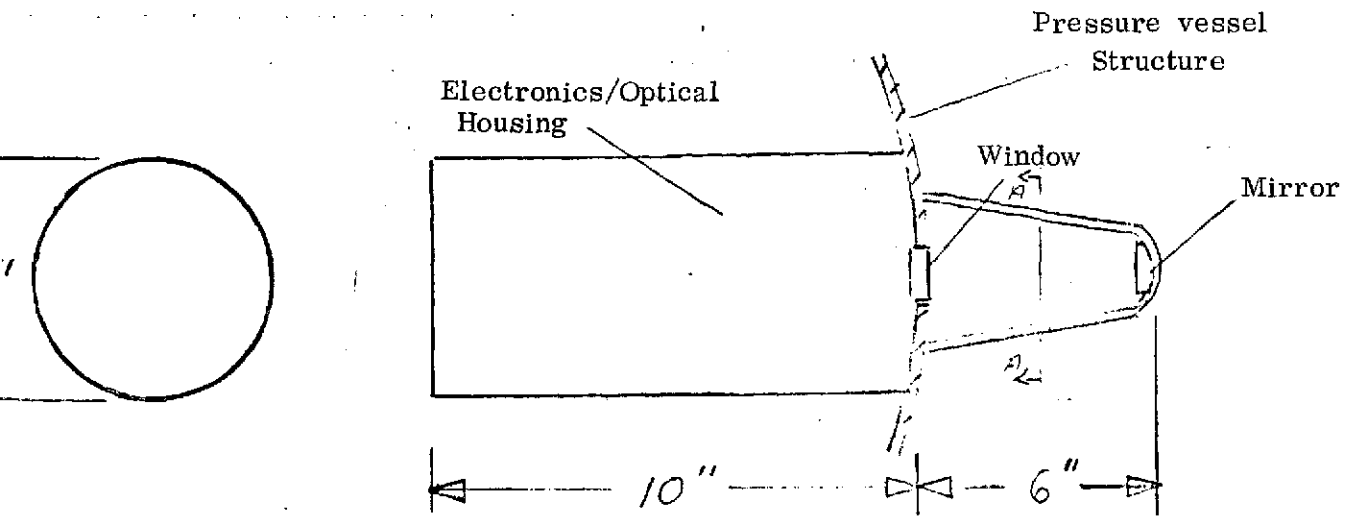
Lou showed me a sketch of the device installed in a heatshield/structure. He could not release it to me until they have reviewed it further, probably two to three weeks. The small heatshield dimension at the stagnation point ( $\approx 3/8"$ ) did not appear to be a problem. The sketch shows a similar dimension, however, the internal layout is perhaps the important factor. It was obvious that this installation requires some iteration with Ames and the experimenter, as such we should attempt one or more feasible layouts for our design. The installation sketch, as best I could remember is attached.

I should make note again of Ames' (experiment office) intent of providing experiment interface data in somewhat more detail than before in about two to three weeks.

  
A. M. Lauletta

AML:vv

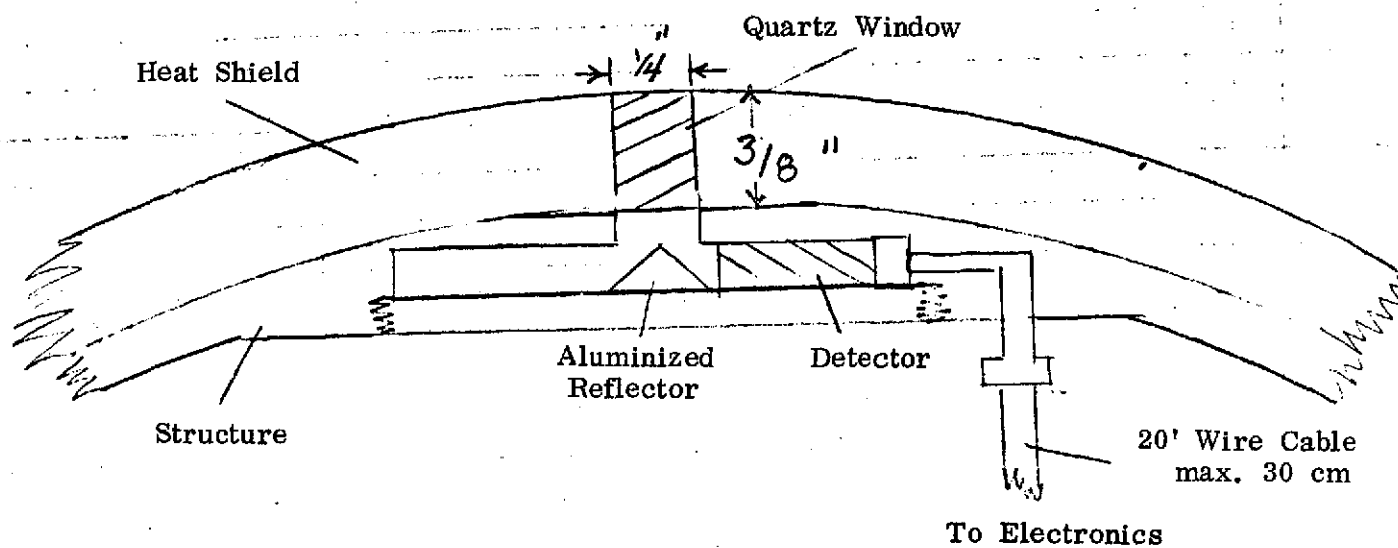
Attachments - 2 pp.



VIEW A-A

SKETCH  
CLOUD PARTICLE SIZE ANALYZER

*cmf 11/10/72*



SKETCH  
SHOCK LAYER RADIOMETER INSTALLATION

*Amf 11/10/1*

## 7.0 INTERDEPARTMENTAL CORRESPONDENCE

**TO:** S.D. Dorfman  
**ORG:**

**CC:** Distribution D

**DATE:** December 5, 1972  
**REF:** HS507-0324

**SUBJECT:** Summary of Splinter  
Meeting on Experiment  
Integration

**FROM:** L.K.Acheson/A.M.Lauletta/  
C.C.Thorpe

**BLDG.** 376 **MAIL STA.** 11141  
**EXT.** 8 /82479/81997

### ATTENDEES

**NASA/ARC:** Joe Sperans, Lou Polaski, Dave Sinnott, Joe Lepetich,  
Dr. Don Hunten, J. Nothwang, R. Jackson, Dr. Larry Colin,  
Bill Schmidt, Ted Brown.

**HAC:** Tony Lauletta, Lou Acheson, Chris Thorpe, Duncan MacPherson.

The charts presented at this session are attached.\* Significant comments which arose are summarized below under the chart where they occurred.

### TASK MILESTONES

Tony reviewed the study task schedule and pointed out the payload definition on 2/1/73 as being significantly different than that which was presented at the kick off meeting. Sperans said we would have to live with it for now but he would supply informal updates, the first prior to December 20th.

### SCIENCE CONTACT CHART

Sperans mentioned that there were six proposals for the orbiter UV spectrometer. Spin rate requirements for the UV were discussed. Sperans asked if the University of Colorado had specified any rate, and Tony said yes, about 5 rpm.

### EXPERIMENT INTEGRATION STUDY TASK CHART

Sperans said that the Microwave Radiometer study should not be continued, and Colin pointed out that this should be put in the contract. Sperans mentioned that the Electric Field Detector and the Solar Electron Detector had also been deleted from the orbiter "other candidate instruments" list as low priority instruments.

Hunter objected to the use of "upper atmosphere" in the title of EX-10, and suggested that stratosphere was a better term to use, since "upper atmosphere" generally has a different meaning.

Sperans commented that the 5Y number used in the magnetometer study was a good one. This number is being used in the NASA/ARC baseline. Chris pointed out that it costs considerably to get, and there was discussion of how one can get an estimate of this cost, which has really never been done before.

\*See HS 507-0022-45, A Systems Design Study of the Pioneer Venus Spacecraft, Informal Review, 1 December 1972.



Regarding the magnetometer for the small probe, Colin thought that 100  $\gamma$  seemed high, but Sperans said it was a good design value. Chris pointed out that even 100  $\gamma$  will be difficult to meet, and Hunten said that if these are the facts of life, then this needs to be said. Sperans mentioned that he had heard the suggestion earlier of reducing the science instruments, and it seemed to him that the small probe magnetometer was the place to start (but this was not an official priority).

With regard to SP-4, Sperans thought it would be very useful to know the differences in experiment interface specifications for the Atlas Centaur. Polaski had compiled a list of items useful to experimenters that he wanted to make sure were in the interface specifications. These included:

- o Grounding scheme - to reduce spacecraft charge it is necessary to have all negative grounds.
- o Signal formats - whose responsibility is it for the bits which identify experiment words within a frame - does the experimenter have to do this out of his bogey, or the spacecraft?
- o Electrical connections - would like to know whether standardized connectors are specified and provided, as well as other interface hardware, buffer circuits, etc.
- o Mounting requirements - thermal and electrical footprints.
- o Dimensional system for the orbiter - important since one will be working with the Europeans.

Polaski also mentioned that several experimenters have expressed a desire for knowing the rotational position of the large probe and the small probe.

#### EXPERIMENT REQUIREMENTS IMPACTING LARGE PROBE DESIGN

Hunten felt that one shouldn't say "none" for the temperature gauges. They have to be specially insulated from the spacecraft. Tony said that this was a design problem that was in hand.

Hunten asked if Hughes thought that ambient heating was better than active heating for the mass spectrometer inlet, and said that it will surely end up with active heating. Tony said this was picked as a worst case situation. Sperans commented that this area will not be defined for a long time.

Polaski complained that he had given Hughes a new configuration for the cloud particle analyzer and it didn't appear in the briefing or the experiment data book. Tony said this hadn't been considered an official change yet. Polaski said this will show up in the configurations they give us shortly.

Regarding up and down viewing for the solar radiometer, Hunten said that Hughes should tell the experimenters that there must be separate up and down instruments as a ground rule for their design. Chris mentioned that one experimenter wanted no window, and Polaski said that all proposals have windows.

Hunten asked whether the probe design could be simplified if the Aureole Detector did not require spin. He said that a number of people on the SSG don't think the aureole part of this experiment is very necessary. If spin control has to be provided just for this instrument, it wouldn't be worth it. Extinction studies could be done with a hemispheric sensor.

Polaski mentioned that the nephelometer was one of the experiments that would like to have an azimuth reference. Hunten agreed with "like to know" but felt they don't really need it.

Tony stated that Hughes was assuming we would furnish the transponder since it is an important element of the communication system even though it is listed as an experiment (DLBI). Ames agreed to resolve this approach.

#### EXPERIMENT REQUIREMENTS IMPACTING SMALL PROBE DESIGN

Hunten asked about the possibility of placing the light source outside and the detector inside for the nephelometer. Chris said we were considering this option. Hunten said that no spin was required for the small probe nephelometer.

Regarding the magnetometer spin, Tony asked whether a reverse of spin direction would cause any problem. After some discussion it was concluded that it did not if one knows the pointing at all times, but otherwise it would.

Regarding the stable oscillator, Sperans said that they were expecting a report from Dr. Shapiro momentarily that would refine his calculations, however,  $10^7$  is not a stable oscillator. Hunten said that a stable oscillator is already a fall back position from a transponder, and that if one had to back off further he didn't know whether it would be worth having. He said that one part in  $10^9$  represents a 30 cm uncertainty.

Tony suggested the stable oscillator also be furnished by Hughes because of its intimacy with the communication system. Ames agreed to resolve this question.

Joe indicated that the stable oscillator studies at Ames (or their contractor) was not considering using phase change material, but some other technique for frequency stability. He mentioned, if we were and it required additional volume, it was not by Ames direction. Tony indicated that this area needed further clarification and should be discussed with Newlands of Hughes and Grant of Ames.

#### EXPERIMENT REQUIREMENTS IMPACTING ORBITER DESIGN

Polaski said that there was not a firm requirement for velocity pointing for the neutral mass spectrometer, but for the moment that was a good assumption.

Hunten asked about the ease of providing an X-band occultation capability. Tony pointed out that it depended on whether a mechanically or electronically despun antenna was used, but also that X-band occultation was now an "other candidate instrument".

## EXTERNALLY MOUNTED LARGE AND SMALL PROBE EXPERIMENTS

Hunten pointed out that the last Venera said it saw light at the surface, so we must look for it even if we don't believe it. Tony pointed out that this did not mean that the aureole detector had to survive to the surface, since the solar flux instrument would have this capability.

## ORBITER EXPERIMENT POINTING PREFERENCES

Regarding the ion mass spectrometer, Tony mentioned that one might want to have it on at higher altitudes than the primary measurement region shown. Chris said possibly over the entire orbit (per a comment by McElroy). Colin expressed surprise, and said he didn't feel one would want it on over the entire orbit. Hunten said that nobody knows over what altitude range it will work.

## SMALL PROBE INSTRUMENTS EXTERNAL VIEW

Sperans mentioned that they are exploring the possibility of reducing the nephelometer volume, and will give us new data on the nephelometer.

Hunten said that the stable oscillator is an important experiment unless we tell them that the probe won't follow the wind.

Sperans said that it looks like a drogue chute will be necessary if one is to achieve a stability better than 10 degrees on the large probe pressure vessel.

## ORBITER

Colin asked why the solar wind probe was now off our design. Sperans said that it had been put in the "other candidate instrument" because we already had a 60 pound payload. Colin and Hunten said that the VOSSG has the solar wind probe back on (the VOSSG report will be out by the end of this month). Colin further said that he didn't think the solar wind probe would be the first to go in cutting the VOSSG 66-pound payload.

## DELTA ORBITER BASELINE

Sperans asked why the Radar Altimeter antenna was now located on the same side as the communications antenna, instead of being in the same place as the previous microwave radiometer antenna. Tony reviewed some of the placement considerations.

## EXPERIMENT INTEGRATION PROBLEM AREAS

Sperans asked what the weight of the magnetometer boom was in the Hughes design. Tony said he could provide it. Sperans said that the VOSSG was talking about a ten foot boom (for a 0.2  $\gamma$  background), and also of putting two magnetometers on the orbiter.

Hunten asked about the targeting of the probe bus. He feels that the experimenters will require a minimum entry angle for maximum observation time. MacPherson said that you would only gain a few additional seconds. Sperans quoted a total

measurement time of 40 seconds and said a few seconds could make a difference. Hunten questioned the few seconds number when comparing a 15° entry and a 90° entry. MacPherson said that when one considered trajectory dispersions one couldn't enter that shallow and still have confidence in entering. Polaski said there was still about a 30-second lifetime. Colin asked if we could give any figures for the altitude of burnup. MacPherson said that the orbiter could operate down to 150 km with no problem, but that one could not get more than another 20 or 30 km for either the orbiter or the probe bus. Hunten said it would be useful to have a refined analysis, and that many people were interested in this question at the present time. Sperans said it would be useful if just a few more measurement cycles could be carried out during the entry.

#### ACTION ITEM REPORT TO FULL ASSEMBLY

Lauletta reported the following action items:

- o Hughes will look at the question of targeting the probe bus for maximum measurement times.
- o Ames will provide a payload update within the next few weeks (by 20 Dec.).
- o For the orbiter, Hughes has been told to delete the microwave radiometer, electric field detector, and solar electron detector from the "other candidate instruments" and to add the solar wind probe to the nominal payload. Hughes should also delete the microwave radiometer study task.
- o Ames agrees with the 5 γ and 100 γ design goals for the probe bus and small probe magnetometers.
- o Hughes will provide a rotational reference for the large probe (to a few degrees).
- o Hughes will provide electrical heating for the mass spectrometer inlet on the large probe.
- o Hughes will switch to the new configuration (bridge structure) provided by Ames for the cloud particle size analyzer.
- o Ames will provide Hughes with priorities for the science payloads to allow payload reduction studies.
- o A meeting will be held for Ames to review the Hughes experiment engineering data book.
- o Ames will determine if the transponder and stable oscillator will be contractor furnished, as recommended by Hughes.

## ADDITIONAL SCIENCE DISCUSSION AT SUMMARY SESSION

Terry Grant stated that a  $10^9$  oscillator stability was not required for DLBI (which may only require  $10^7$ ) but for the doppler component of velocity.

The VOSSG only considered a mid latitude periapsis, type 2 orbit, but Hunten considers the limited time on the dayside to be a fairly serious deficit. Ames will look at the orbit selection considerations and comment relative to it.

The question has come up recently as to whether there is a requirement on the star sensor to work with either northern or southern hemisphere stars.

There is interest in the use of accelerometers in the probes to measure atmosphere turbulence.

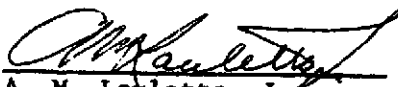
The VOSSG has recommended a spin axis perpendicular to the ecliptic (unless there is a significant decrease in cost for another orientation).



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L. K. Acheson

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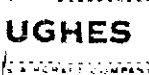
C. C. Thorpe

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A. M. Lauletta, Jr.

LKA:CCT:AML:vv

Attachment - 26 pp.



8.0 INTERDEPARTMENTAL CORRESPONDENCE

TO: Distribution D	CC:	DATE: 11 December 1972
ORG:		REF. HS 507-0338
SUBJECT: Minutes of Meeting with J. Sperans and L. Polaski		FROM: A. M. Lauletta
		ORG.
		BLDG. 376 MAIL STA. 11141
		EXT. 8-4509

On December 8, 1972 J. Sperans and L. Polaski visited Hughes to review and provide updated information on Pioneer Venus experiments and experiment requirements. The experiment engineering data book was used as a reference baseline to review all nominal payload instruments.

Significant new information was obtained. As a result, all areas should review these requirements carefully. The data book will be modified to incorporate these changes to the baseline. Sperans indicated that this was probably the last update he could provide us until next February. The 20 December update will reflect these changes and possibly additional changes to the Orbiter, but none were expected. A prioritized payload was not discussed.

I would like to highlight the significant areas; the detail notes follow:

- Significant changes in telemetry, more analog data channels, 10 bit encoding, and adaptive sampling.
- Requirements for unregulated power in the probes.
- Possible volume reduction of the stable oscillator for the small probes.

- Addition of the Solar Wind Probe to the nominal Orbiter payload.
- Retargeting of probe bus for maximum observation time, not necessarily on sun side.

### General

- Data formatting is generally quite different than given in the data book, with a large amount of analog data coming from the experiments. Updates have been provided for most of the multiprobe instruments.

### Large Probe

- The temperature gauge requires 10 bit accuracy for turbulence measurements.
- The temperature gauge should be fixed, not deployable.
- Most experiments require unregulated power only.
- Pressure ports must be mounted 180° apart in forward hemisphere.
- One output of the accelerometer will be a turbulence measurement with 20 7 bit samples per descent.
- The neutral mass spectrometer must be turned on at least 15 minutes before entry to activate the ion pump.
- The question of whether electrical heating is required for the mass spectrometer inlet is still in controversy, despite Hunter's comments on 1 December.
- There is an integration problem with the mass spectrometer in that it must be completely baked out and installed as a sealed instrument early in the probe assembly stage.

- Power required for the new cloud particle analyzer configuration is 10 watts, and not 40 watts as previously reported.
- There are three contenders for the Solar Radiometer (now called the Solar Flux experiment) -- Ames, Weinman, and Goddard. We are using the Weinman, which is in some ways a worst case. The Ames proposal has a single port looking out to the side with a mirror oscillating over  $\pm 45^\circ$ . Volume of this instrument is  $325 \text{ in}^3$ , and it requires 10 analog outputs.
- The nephelometer is completely up in the air, but one alternative worth investigating is a pulsed tunable dye laser proposed by the Desert Research Institute at the University of Nevada in Reno.
- There is concern about window contamination of the shock layer radiometer, primarily from ground handling and rocket exhaust, not heat shield ablation.
- Providing an azimuth reference is not required for the baseline design, but it is desirable to know how much it would cost. The wind-drift radar at the present time is the only instrument definitely requiring azimuth.

#### Small Probe

- The volumes of most instruments are being reduced. Original estimates were too conservative.
- There is no requirement for turbulence measurements by the small probe accelerometer.
- The stable oscillator is now specified as having a weight of 0.36 lb and a volume of  $3 \text{ in}^3$  (rather than  $40 \text{ in}^3$ ). Newlands should call Terry Grant to verify these numbers.



### Probe Bus

- Forget about the SSG recommendation to target the probe bus in the vicinity of the large probe, and look at shallow angle entries for maximum observation times.
- The UV Fluorescence experiment has a strong desire to enter on the dark side, since its sensitivity is way down on the day side. All other experiments have a weak preference for the day side. These about balance and make it a toss up as to which side to enter.
- The electron temperature probe should be mounted perpendicular to the velocity vector and the preferred spin rate is equal to or less than 5 rpm.

### Orbiter

- The 20 December update will provide some new information on orbiter instruments.
- The orbiter magnetometer will probably be a European instrument. The Europeans have a strong desire to measure 0.2 $\gamma$ , but don't change from present 5 $\gamma$  baseline yet.
- The maximum altitude at which measurements are desired for the ion mass spectrometer is 4 or 5 thousand kilometers.
- It would be desirable for Hughes to continue to gather data on orbiter instruments from experimenters. Sperans suggests that it would be particularly desirable to contact the following:

- Gille at NCAR
  - Broadfoot at Kitt Peaks
  - Freeman at Rice
  - Houghton at Oxford
  - Ackerman in Brussels
- 
- It is difficult to make a case for X-band occultation from a science standpoint; L-band would be far preferable. The problem is that ground stations are not instrumented for L-band, except Arecibo.
  - Because of atmospheric refraction it is very desirable to have a scanning capability during occultation. Talk to Kliore at JPL regarding this.
  - On the R.F. altimeter, it would be desirable to talk to Walt Brown at JPL, who seems to have a different approach and talks about a 3 lb. radar.

  
A. M. Lauletta

AML:cjb



## 9.0 INTERDEPARTMENTAL CORRESPONDENCE

TO: Distribution D

CC:

DATE: January 9, 1973

ORC:

REF. HS507-0377

SUBJECT: NASA's Planetary Program  
Past-Present-Future

FROM: L.K. Acheson

ORG. 40-91

BLDG. 376 MAIL STA. 11141

EXT. 8-1086

On 29 December 1972 an all-day session on NASA's Planetary Research was held in Washington D.C. as part of the annual AAAS Meeting.

Attached is a program of the meeting and a transcript from my notes of the opening talk by John Naugle, which provides an overview of the NASA planetary program at the end of the first decade of planetary exploration.

Reports on the other talks will be issued later.

L. K. Acheson

Attachments 1 and 2

LKA:vv

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NASA's PLANETARY RESEARCH

Friday, December 29, 1972

Washington Hilton (Monroe)

9:00 a.m.      Chairman      Homer E. Newell  
Associate Administrator, NASA

NASA Planetary Program - Past-Present-Future  
(Space Probes and Ground Based)

John E. Naugle (Associate Administrator for Space Science,  
NASA Headquarters, Washington, D.C.)

Mars - After Mariner 9

Surface

H. Masursky (Chief Scientist, U. S. Geological  
Survey, Flagstaff, Arizona)

Atmosphere

C. Leovy (Associate Professor, Department of  
Atmospheric Sciences, University of Washington)

The Mysteries of Venus

T. Donahue (Professor, Department of Physics,  
University of Pittsburg)

2:00 p.m.      Chairman: Homer E. Newell

Magnetic Environment of the Planets

W. I. Axford (Professor, University of California at  
San Diego)

Atmospheres of Mars, Venus Earth - A Problem in Atmospheric  
Evolution

S. I. Rasool (Deputy Director, Planetary Programs  
NASA Headquarters, Washington, D.C.)

Planetary Exploration and the Future of Man

R. Jastrow (Director, Goddard Institute of Space Studies  
New York)

## 9.1 NASA'S PLANETARY RESEARCH

### NASA PLANETARY PROGRAM - PAST, PRESENT, FUTURE

(Space Probes and Ground Based)

John E. Naugle (Associate Administrator for Space Science,  
NASA Headquarters).

Although man has been speculating about the planets and stars for ages, the first quantum jump in knowledge came from the Galilean telescope, and the second quantum jump came from radio and radar astronomy after World War II. The third quantum jump occurred on 14 December 1962 when Mariner 2 flew by Venus, and the character of planetary observations changed completely. In the decade since then we have passed from simple flybys to orbiters and have answered questions men have had for centuries.

Our exploration of the planets is different from past explorations. We have no intrepid band of adventurers, but automated spacecraft. However, don't be misled by this substitution to think that the information brought back is of little value. It is directly applicable to knowledge of the earth. The dynamic process of the global dust storm on Mars is useful to people studying the effects of pollution on our atmosphere. At present our knowledge of planetary atmospheres is so limited we don't know what would happen if there were a one percent increase in the solar radiation falling on the earth.

I want to give a perspective of the planetary exploration program. If one had a celestial TV system looking down on the solar system with a cosmic tape recorder running over five billion years one could answer such questions as: is the temperature of the earth slowly changing, and which way; is life unique to earth or does it exist on other planets, or can it spread to other planets. We don't have such a fancy TV system, the closest thing to it is the human mind. For the past decade, we have put some significant things on the tape recorder.

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If we zoom in our TV camera on Washington in late 1972 we now get another perspective. Planetary research is clearly a major element of the US space program, which has three overall purposes, the third being exploration, which means exploration of the planets.

Thirteen spacecraft have traveled to planets in the last decade, six US and 7 SU. Pioneer 10 is on its way to Jupiter. Six more US spacecraft are on the way. Thus the outlook for planetary research looks good to me.

When one begins to plan, one deciding factor is launch opportunity. For Mars opposition occurs every 26 months, for Venus every 19 months, for Jupiter every 13 months. One can get to the outer planets only by using Jupiter. Jupiter/Saturn and Jupiter/Uranus opportunities occur less frequently.

Another aspect is cost. It costs 140 million for a pair of Mariner class orbiters; and slightly less than 100 million for the Pioneer class. The total budget for planetary research is a little over 300 million annually, of which two-thirds currently goes to Viking. This is a substantial amount of money. Ten thousand people work directly on planetary research, or one out of every twenty thousand people in the country. When the history of this period is written, these people will have done much more than their share of contributing to earth's development.

We also use ground-based instruments for planetary studies. NASA has supported the new large optical telescopes at McDonald Observatory and Mauna Kea, Hawaii. Twenty percent of the astronomical research in the country is supported by the Planetary Program. The Planetary Patrol first observed the dust storm on Mars.

I will now turn to what we have done in the past decade, first considering Venus.

#### Venus

Mariner 2 flew by Venus on 14 December 1962 at 35,000 km altitude, and discovered that Venus had no magnetosphere and a high surface temperature. On the way to Venus it found a radial solar wind of protons at 300 to 500 km/sec which was steady but gusty.

Five years later, in October 1967, Venera 4 entered the Venus atmosphere as a probe, and Mariner 5 flew by at 3900 km. They discovered that Venus had a CO<sub>2</sub> atmosphere with only traces of water vapor, the surface temperature was at least 500°K, and the surface pressure at least 26 atmospheres.

Venera 5 and Venera 6 in May 1969 confirmed earlier results. Venera 7 in December 1970 extended the temperature profile data to the surface and found a temperature of 750°K and a pressure of 95 atmospheres. Venera 8 on 22 July 1972 found that the surface composition resembles granite rock on earth, and that a certain amount of visible light penetrates to the surface. It also measured small amounts of ammonia in the atmosphere. It further confirmed the Mariner 5 result of equal surface temperatures on the day and night side.

From ground-based radar measurements, it has been determined that the Venus rotation period is very slow and retrograde, and that the Venus surface has a relief structure.

First order questions about Venus include: the nature of the clouds, the number and composition of the cloud layers; the global circulation of the atmosphere; why Venus has such a high surface temperature and why the CO<sub>2</sub> is stable; does Venus have a magnetic moment; and what are its seismic characteristics.

A future mission is Mariner Venus/Mercury, which will fly-by Venus in February 1974 and Mercury in March 1974. This will provide the first images of the Venus clouds and the Mercury surface. It will make measurements of atmospheric composition and structure, temperature gradients, magnetic fields, and energetic particles, and the mass and radius of Mercury.

Under study are Pioneer/Venus 77, a multiple probe mission to determine global circulation, precise atmospheric composition, and structure of the clouds; and Pioneer/Venus 78, an orbiter that will provide high resolution radar maps of the surface, measure the upper atmosphere structure, and map fields and particles.

## Mars

The exploration of Mars began with the July 1965 fly-by of Mariner 4 at 9800 km. A low atmospheric pressure 1/100 of the earth atmosphere was discovered and a cratered surface. It was concluded that Mars was a dead planet. (This conclusion has not stood up.)

Mariner 6 and 7 fly-bys in July and August 1969 determined the atmospheric composition and surface temperature, and observed a chaotic terrain. The polar ice cap was determined to be CO<sub>2</sub>.

In November 1971 the Mariner 9 orbiter arrived at Mars together with the Mars 2 orbiter/lander, followed in December by the Mars 3 orbiter/lander. Mars 3 successfully ejected a soft-landing capsule, which was short lived. The orbiters detected a weak planetary magnetic field, and low exospheric temperatures. Mariner 9 mapped the complete surface, discovering volcanos, rift valleys, and wind fields. The effects of a global dust storm were observed. Polar water ice was detected, and a seasonable variation of the atmosphere. Mars has turned out to be a lively planet.

An approved mission is the Viking June-August 1976 orbiter/lander, which will study the biology, organic and inorganic chemistry of the surface. It will also determine atmospheric structure and composition, take images of the surface, study meteorology, H<sub>2</sub>O distribution, and the detailed heat balance of the planet. Soviet Union plans are not known. Regarding future missions, in September 1979 there might be a powered Viking lander mission.

## Outer Planets

With regard to the outer planets, all we know is from optical and radio telescopes.

In 1972 Pioneer 10 was launched toward Jupiter and will fly-by in December 1973. It will measure the Jovian environment, radial gradients of cosmic rays, magnetic fields, plasma, and the heat balance of Jupiter. It already has told us the asteroid belt is not a hazard.



In 1973 Pioneer G will be launched to fly-by Jupiter in January 1975 with the same mission as Pioneer 10.

In 1977 Mariner Jupiter/Saturn will be launched to fly-by Jupiter in 1979 and Saturn in 1981. This will provide high resolution imaging of Jupiter, Saturn, and a number of their satellites. Also atmospheric structure and composition, possible atmospheres on satellites, particle and field environment of planets, radial gradient of low energy cosmic rays up to 10 A.U. and beyond will be measured.

There will be 20 opportunities till 1980 for swing-by flights and we have chosen the 1977 Earth, Jupiter, Saturn flight. The Russians have no plans for such outer planet missions. Missions preferred by the Science Advisory Group are:

1976 Pioneer Jupiter/out of ecliptic -	1 mission
1979 Mariner Jupiter/Uranus fly-by -	2 missions
1979 Pioneer entry probe to Saturn -	} - 3 missions
1980 Pioneer entry probe to Uranus via Saturn fly-by)	
1981 Mariner Jupiter Orbiter -	2 missions

The most exciting results of planetary exploration will probably come from the outer planets.

In summary, we have had an active and profitable decade of planetary exploration. There has been substantial improvement in the quantity and quality of missions. In the decade ahead, a number of missions are planned for an even more fruitful period. It will always be an interesting enterprise. Perhaps we can, if we take a cosmic perspective, provide the perspective to bring peace and goodwill to earth.

#### DISCUSSION

Question - When does NASA have to get funding for Pioneer Venus and the Outer Planets?

Answer - For Pioneer Venus in Fiscal Year 1974 funds.

Question - Regarding the budget, what is NASA doing to get information out to the people? For example the new map of Mars is unavailable.

Answer - It is our intention to give widest possible distribution of this map, but we wanted it to be as complete as possible before distributing. It should be out within a month.

Question - How can you possibly give up the opportunity for the Grand Tour?

Answer - The primary reason is the amount of money involved. It would take 700 to 800 million dollars over a considerable period.

Question - Does NASA plan any cometary exploration or unmanned exploration of the moon?

Answer - Studies are going on with regard to comets. I deliberately didn't talk about comets, interplanetary, or lunar missions. Automated missions to the moon have been considered but there are no firm plans.

Question - Are there plans for space vehicles that would widen the launch opportunities?

Answer - We are looking at various exotic propulsion systems such as solar electric, but there is still a tremendous tendency to use these at a given launch window, because we can get greater weight or shorter time. Also, a rigid window is not all that bad from a managerial and cost standpoint.

Question - Can you comment on the possibility of returning to Mars with a lander in 1979?

Answer - It is possible, but we cannot say now.

## 9.2 THE MYSTERIES OF VENUS

T. Donahue, Professor of Physics, University of Pittsburg

Despite the fact that Venus is the third brightest object in the heavens, and much nearer the twin of Earth, and has been visited by Soviet probes, we know much less about it than we do about Mars. For one thing the United States has been much less active than in Mars exploration and also Venus hides itself under a veil of clouds. But various investigations have told us a great deal about Venus and the class of problems that exist.

Radio astronomical studies have told us that its radius is 6050 km  $\pm 5$  km, its orbital period is 220 days but it rotates in a retrograde direction with a 250 day day. Sunrise occurs every 118 days in the west. The surface is not smooth but has a relief function of several km.

Earth based spectroscopic measurements have yielded the following:  
(aided by the Venera data)

CO <sub>2</sub>	95 $\pm$ 5%
O <sub>2</sub> /CO <sub>2</sub>	$5 \times 10^{-6}$
CO/CO <sub>2</sub>	$4.6 \times 10^{-5}$
H <sub>2</sub> O/CO <sub>2</sub>	$10^{-4}$ - $10^{-6}$
HCl/CO <sub>2</sub>	$6 \times 10^{-7}$
HF/CO <sub>2</sub>	$5 \times 10^{-9}$

The atmosphere is extra dry.

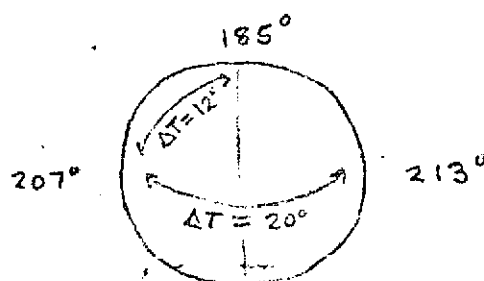
From seven of the Venera probes plus Mariner 5, the surface pressure is 90 atmospheres, the surface temperature is 750°K and there is an 8.6°/km lapse rate all the way to the surface.

The most obvious question is, what is the nature of the clouds? There is a thin cloud layer at 81 km (3 mb) and 175°K which is believed to be HCl H<sub>2</sub>O. There is a thick cloud layer of unknown composition at 61 km (240 mb) and 260°K. Below these two cloud layers are probably other cloud layers.

The composition of the clouds has vexed people. Water ice is not defended by very many because polarization measurements indicate spherical drops with an index of refraction  $n = 1.45$ , whereas ice is hexagonal with  $n = 1.33$ . The most popular model is HCL  $H_2O$  which according to Lewis is spherical with  $n = 1.40$ .

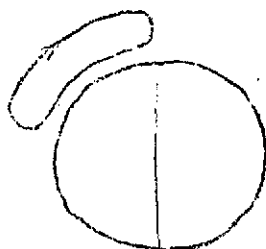
One of the high priorities for Pioneer Venus is a careful study of the nature of the cloud particles.

Temperature can be studied by radiometry. The most significant fact besides the high temperature is the low temperature gradients. At the surface



the temperature gradient is 12 degrees from equator to pole, and 20 degrees from day to night. Temperatures near the cloud tops are shown above.

One has a very dense atmosphere in a slowly rotating planet. It is more like the circulation of an ocean than the air of Earth or Mars. Goody and Stone have a model in which solar energy is deposited at the top of the clouds and a Hadley cell is formed as shown.



There is a 4-day circulation which corresponds to 100m/sec horizontal winds at the cloud tops, confirmed by ground based measurements. There are not any winds near the surface of more than a few cm/sec. ( $1\text{m/sec} > v > 1\text{cm/sec}$ )

Venera 8 has discovered a granitic character of the surface. From the passive  $\gamma$ -ray spectrum, there is 4% K,  $2 \times 10^{-4}\%$  U, and  $6.4 \times 10^{-4}\%$  Th. Venera 8 also measured  $10^{-2}$  -  $10^{-3}$   $\text{NH}_3$  at altitudes of 33 to 46 km. There was reported to be a significant amount of light at the surface, and a difference between night and day (the probe entered near the terminator).

Most fundamental is the difference in the composition of Earth, Mars, and Venus. Why is there no water, no ocean in Venus. It is well known that  $\text{H}_2\text{O}$  dissociates into H and hydroxyl (HO). At the top of the atmosphere H can escape. On earth it escapes at a rate of  $10^8/\text{cm}^2/\text{sec}$ . One explanation of the lack of water is that on Venus an H escape rate of  $10^{11}/\text{cm}^2/\text{sec}$  would be required, which is three orders of magnitude greater than on earth. There is not yet any practical mechanism for this. Also there is the question of what to do with the O left behind. It would require 100 km of crust to be gardened and turned over. Therefore this is not the answer.

Another explanation by Lewis at MIT, following in Urey's footsteps, is based on the equilibrium theory of the solar system. In the model of the solar nebula the temperature in the neighborhood of Venus would be so high that water would never condense. In fact one can't explain the amount of water which is observed. It would require a collision with a comet to explain.

On earth oxygen may have arisen from photosynthesis. Why is so little oxygen present as  $\text{O}_2$  or CO on Mars and Venus? How is it that the atmosphere remains as  $\text{CO}_2$  when solar UV dissociates it readily into CO and O at a large rate? CO and O do not readily recombine with one another. It is a very slow process.

In the upper atmosphere of Mars the concentration of oxygen is 3/4 of 1% of  $\text{CO}_2$ . Solar radiation could destroy all  $\text{CO}_2$  in 3000 years, and all oxygen in 3000 seconds. Therefore atomic oxygen must be transported very rapidly out of the upper atmosphere down into the lower atmosphere, but in the lower atmosphere O wants to make  $\text{O}_2$ . To work on Mars, the vertical transport must be more efficient than on earth by many orders of magnitude. If this is the explanation for Mars, is it also for Venus? The process on Venus may be aided by chlorine.

In summary, there are a whole series of problems to be addressed to the planet Venus, and provided the Gods are willing, the carefully orchestrated series of probes known as Pioneer Venus will answer this problem in the next decade.

### 9.3 Atmospheres of Mars, Venus, Earth - A Problem in Atmospheric Evolution

S. I. Rasool (Deputy Director, Planetary Programs, NASA Headquarters).

I will talk a little bit about what we know today. Five years ago here at the AAAS I gave a talk on the evolution of the earth's atmosphere. At that time I said that about 4.5 billion years ago the earth formed and had an atmosphere derived from the solar nebula from which it condensed. A billion years later it lost its first atmospheres and formed a second atmosphere from the interior (volcanic action). This is also the time when life started at the surface of the earth. From that time the composition of the atmospheres and ocean have changed slowly. But now the composition of the atmosphere is changing rapidly due to industrial wastes.

New since then is data on Mars and Venus, about the same in size and mass (factor of 2 in size, 10 in mass), but their atmospheres are completely different. The surface of the earth is the only place we have liquid water, which is very important for the evolution of life.

#### Composition by Weight

Human Body		Ocean, Air, and Sediments	
O	65	O	78
C	18	C	8
H	10	H	8
N	3	Ca	4
Ca	2	N	1

An important question is whether these were oceans on Mars or Venus earlier. This is related to the cosmic evolution of things. To quote George Wald, "living things are a late outgrowth of the metabolism of our galaxy". The most important results to come from the planets will come from biology.

We have formation of the planets from a solar nebula. Input processes to the atmosphere are: capture from a primitive solar nebula, capture from the

solar wind, collision with comets and meteorites, outgassing from the interior, chemical reactions with surface materials. Loss processes are thermal evaporation, sweeping action of the solar wind, chemical reaction with surface materials, rotation instability of the planet. These are the input and loss processes which may change the composition of a planetary atmosphere.

Composition of the solar nebular included, H, He, C, O, Ne, N . . . .  
In the stars everything is in a gaseous state. In planets of 300 to 500 degrees the elements are solid, with some exceptions.

Initial composition of a planetary atmosphere at the time of the planet's formation is estimated to be, by weight:

H <sub>2</sub>	63.5
He	34.9
H <sub>2</sub> O	0.6
Ne	0.34
CH <sub>4</sub>	0.26
NH <sub>3</sub>	0.11
A <sup>36</sup>	0.15

This is almost exactly the atmosphere of Jupiter.

With respect to the escape fluxes for various planets, the earth and Venus in 10<sup>9</sup> years will lose most of the H and HE, Jupiter will lose nothing, Mars will lose everything.

The first surprise is when you look at earth. H and He are missing, but also C and N are missing by large factors. This is evidence that all of the original atmosphere has gone.

But the atmospheres of Mars and Venus are also secondary in origin (from Ne data). Now we think something happened in the region of the solar system to cause this loss. Computation of gases from volcanos, etc., seems to check the excess available. More evidence is coming from Mars and Venus.

If this is true, we always have had an oxidizing atmosphere, whereas some biologists want a reducing atmosphere to explain life.

How do we account for this? We had more hydrogen in the earlier history. The outgassing has changed. If you have a methane atmosphere the atmosphere is cooler, and the H does not escape as fast. So we started only with a methane atmosphere and water in the ocean.



The first problem is the oxygen balance on the earth, if photosynthesis started 1.5 billion years ago. In the early history of 0 to 1.5 billion years there was no photosynthesis. The atmosphere oxidizes too quickly.

Then, why don't Mars and Venus have water and go through the same evolution as earth.

		Venus	Earth	Mars
		700°K	300°K	230°K
		75 atm	1 atm	0.02 atm
CO <sub>2</sub>		90,000 g/am <sup>2</sup>	70,000 (crust)	
N <sub>2</sub>	atm	3000	800	70 g/cm <sup>2</sup>
	crust	?	2000	1
H <sub>2</sub> O	atm	100	1	0.01
	crust	0	300,000	0.01
O <sub>2</sub>	atm	10	200	
	crust	?	8 X 10 <sup>6</sup>	

How do we explain the end result today. If the volcanic action of Mars is 1000 times less than Earth and Venus we can explain Mars.

There is a temperature versus pressure of CO<sub>2</sub> plateau.



When CO<sub>2</sub> goes through water it forms silicates.

On Venus we start at much higher temperatures and don't touch the liquid phase, therefore on Mars CO<sub>2</sub> is still building up very slowly.

If Earth had been only 6 percent closer to the sun, the water couldn't have formed.

Can this happen now, and the run away greenhouse effect occur? At the present time the oceans are extremely stable. In the ice ages we have had temperatures variations of 6 or 10°, but we now ask if the amount of particulate matter in the atmosphere can change the temperature. It has been shown by several people that CO<sub>2</sub> is not a problem. Particulates in the atmosphere are another problem.

If one increases the optical thickness of the atmosphere by 2 orders of magnitude, then the incoming sunlight is affected more than the outgoing IR radiation.

From the laboratory on Mars, when we went to Mars we saw that during a dust storm the surface temperature was  $7^{\circ}$  lower and the atmospheric temperature was larger.

9.4 MARS - AFTER MARINER 91. Surface - H. Masursky (Chief Scientist, U.S. Geological Survey, Flagstaff, Arizona)

About two years ago a National Geographic article on Mars, based on Mariner Mars 4, 6, and 7, stated that Mars was very moon-like and a dead planet, with nothing happening except for impact processes. Mariner 9 changed this.

The loss of Mariner 8 caused complete redirection of a mission that was two years in planning. An intermediate inclination was chosen to satisfy the objectives.

Two TV cameras were carried:

- low resolution - 1 km/line
- high resolution - 10 times greater resolution

The A camera covered the entire planet, with a 19 day mapping period. The high resolution camera sampled 1% of the planet. Geodetic mapping was carried out from a higher altitude.

When we arrived, we ran into the greatest dust storm ever observed. The planet looked like an orange tennis ball. Four black spots were observed, and it was found that these were also present in 1924 pictures.

After abandoning the compromise mapping plan, we went into a compromise reconnaissance mode. Each of the four dark spots had a complex crater at the top. They are clusters of craters, and look like a product of a complex cycle of volcanic activity (caldera). Greatest of these is Nix Olympica.

A detailed picture of Nix Olympica was obtained after the dust cleared. It extends 8 km or 27 kft above the base. The most puzzling feature is a great cliff at the base of the structure. A high resolution picture gives detailed structure and shows flow going down the side of a volcano.

The enhanced TV image vs the raw image shows a tremendous improvement. Mars 2 and 3 orbiter pictures are low resolution, by comparison.

One photo shows small volcanic domes similar to basaltic shield volcanos on earth.

There are radial ridges on the middle spot. Most of the maria are cut by ridges. They are probably fractures up through the lava base cone, similar to lunar maria ridges.

The high plateau is cut into a mosaic of blocks. There are very few craters in this area. This must be young geologically.

A great rift system runs for 5000 km, and is 6 km deep. This is somewhat similar to the East African rift zone. The UV spectrometer, doing pressure mapping, provided useful data in conjunction with TV maps.

The most interesting thing about the chaotic terrain is the broad sinuous channels, not great masses of debris. The only similarity on earth are areas of permafrost. The melting of permafrost causes collapse of walls.

A completely different kind of channel is on top of a plateau in the Resing area, with complicated tributaries. The only analog is intermittent flowing streams.

There are intricate banded networks in the equatorial region, that appear to be lava channels.

In summary, we have looked at three types of channels that are fluid, one of which is lava.

With regard to polar caps, the south polar cap is near minimum size. There is a dark fork visible. We are still debating how much water is in the residual polar caps. We can't tell from IR. There is a laminated terrain surrounded by etched bed terrain. The polar area is very smooth. Polar ice lies in a depression. This may indicate thicker ice in parts.

The north polar cap comes down to a size similar to the southern, but has a vortex appearance. The north polar region lies in a large plain area. There are bright and dark wind trails.

The central area of the planet has no filled areas. There is enormous dissimilarity between the southern hemisphere and the northern.

The IR spectrometer maps potential continents and ocean basins.

Phobos and Deimos appear to be very ancient bodies, the products of accumulation, and only affected by impact processes.

2. Atmosphere - C. Leovy (Associate Professor, Department of Atmospheric Sciences, University of Washington)

I will present results from Mariner 9 from the viewpoint of a TV participant and dynamic meteorologist.

The atmosphere is very difficult to see from TV, but combined with data from the UV spectrometer and IR interferometric spectrometry, one can infer a great deal about the atmosphere, and what was going on during Mariner 9.

We have progressed from a static view of the atmosphere to a dynamic. We already knew the composition of the atmosphere to be CO<sub>2</sub>, and the pressure.

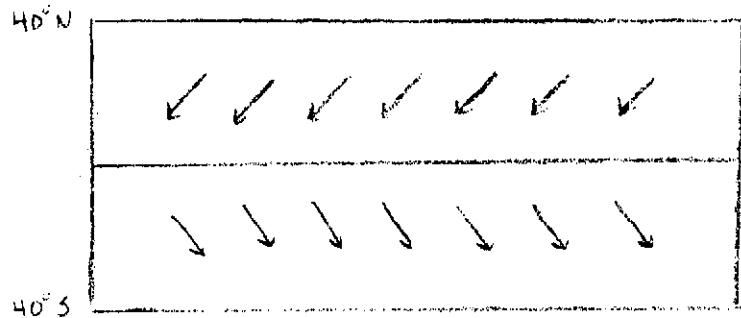
I will discuss two aspects of the dynamics, the types of processes and the exchange of volatiles between the atmosphere and the surface.

Mariner 9 made 2 revolutions/day. The particles in the atmosphere were rather large, because all instruments noted clearing at the same time. They were greater than 1  $\mu$ , with 5 -10  $\mu$  most predominant. Larger than 10  $\mu$  would fall out very rapidly.

A limb feature observed is a condensate layer at 70 km. This is believed to be a CO<sub>2</sub> condensate. Dust extends up to about 50 km altitude and is uniformly mixed. It is also very uniform in the horizontal dimension.

IR data yielded the vertical distribution of temperature during the dust storm. The atmosphere cooled and became more unstable as the dust receded, with winds of 40 m/sec at the surface theoretically. There was a large diurnal variation of temperature, 30°, both at the surface and up to 30 km. The largest temperature difference occurred at 40° latitude.

Global circulation was axially symmetric..



From temperature data one can infer the strength of the winds, which was about 20 m/sec during the waning period of the dust storm.

All of the great dust storms have occurred at periapsis, and start near the polar cap. They require that additional solar energy be deposited, and that the perihelion and solstice be phased together. The latter has a 50,000 year period.

## 9.5 SURVEY OF FIELDS AND PARTICLES MEASUREMENTS

W. I. Axford (Professor, University of California at San Diego)

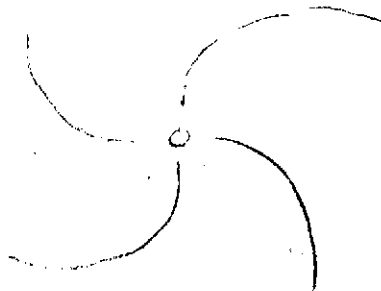
These measurements have been made from the beginning of the space age. The first big discovery was the VanAllen Belts, using a simple Geiger tube and a magnetometer. Some think that Fields and Particles have had their day, but only in the last three years have we been able to measure electric fields properly, and measure low energy particles down to 100 ev.

Particles and Fields in the Solar System - an outline

1. Interplanetary Medium (solar wind)
2. Earth Magnetosphere and Ionosphere (magnetic storms, sub-storms, aurora)
3. Venus, Mars, Mercury, Moon
4. Jupiter, Saturn, Uranus, Neptune, Pluto
5. Comets
6. Distant solar wind, cosmic rays, interstellar gas
7. Out of the ecliptic

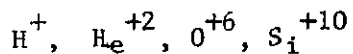
The first indication of the existence of the solar wind was the fact that comet tails always point away from the sun. Twenty years ago it was postulated that this was due to an expansion of material outward from the sun. This solar wind was discovered in 1959 by the first Soviet lunar shots, and is the main cause of everything interesting that happens in the earth's magnetosphere.

The interplanetary magnetic field spirals outward from the sun. This was predicted by Parker and verified by Ness on IMP-1.



Out at Jupiter the magnetic field lines are almost circular.

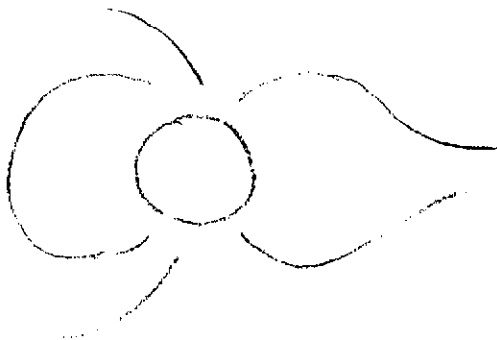
Composition of the solar wind was determined by electrostatic analysis on Vela:



In the Apollo mission, measurements were made by exposing a foil to the solar wind and catching it. This was done to get the noble gas components.

With regard to the magnetosphere of the earth, the aurora is of major interest. At altitudes of about 100 km, fast electrons from the sun interact with the atmosphere.

Much of the effort in terrestrial space research has been to discover the nature of the aurora.



High latitude field lines connect back to the sun. The aurora particles come from the tail region behind the earth and pour into the earth. The storm is due to the injection of solar particles into the magnetosphere.

A solar flare is the nearest analog to a substorm in the magnetosphere. It is a curious non-linear type of thing, occurring in bursts, with energy stored over long periods and then released suddenly.



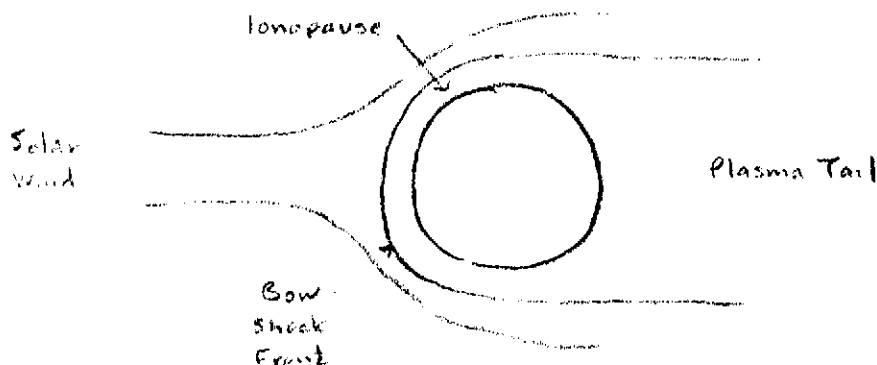
## Survey of Fields & Particles Measurements

Page Three

The earth's magnetic field does connect to the interplanetary field. Solar flares find their way into the magnetosphere very easily along magnetic field lines.

Ionized particles are flowing all over the magnetosphere in bursts or substorms. Perhaps 100 substorms were observed over 8 days with the ATS.

Considering the other planets, the solar wind interacts directly with the atmospheres of Mars and Venus, in a moderate interaction. The moon leaves just a wake in the solar wind, a weak interaction. Mercury may have a very thin atmosphere of  $H_c^4$ ,  $Ar^{40}$  and  $Ne^{20}$ .



Occultation measurements around Venus showed differences in the night side and day side ionization which we still don't understand.

The Russians think that Mars has a small magnetic field, from Mars 3 data.

Jupiter is very exciting. It is the brightest radio object in the sky. One type of radiation is synchrotron emission from general radiation belts. A second type is associated with the satellite Io. It is not clear what causes this, but it tells us the magnetosphere extends out past Io, in fact out perhaps to 50 Jupiter radii. Pioneer 10 will tell us something about this.

Nothing is known about the magnetic field of Saturn, because nobody knows anything about Saturn.

Uranus is unique in that its axis is pointed toward the sun, and so its magnetosphere would be expected to have a different character.

For comets the solar wind produces a plasma tail. There is a large region of disturbance in the solar wind. There are a large number of cometary ions rather than solar wind ions in the tail.

Comet Encke is the most well observed. It appears every 3 years and has been observed 50 times. It is almost dead, and is about to turn into an asteroid stream in the next 50 years.

Some young comets like Halley's comet may be very dangerous, but it should be easy to rendezvous with Encke. With electric propulsion one could rendezvous easily. (Encke may be a large boulder which has come off Halley's comet).

Comets may be the fundamental building blocks in the solar systems. The most interesting comet is Halley's comet, but it is definitely dangerous. It comes in retrograde.

Scheduled is a cometary fly-through and then rendezvous in 1984. Pioneer G could be made to pass through a comet near Jupiter.

Observations of Ly  $\alpha$  from space with OGO-5 found that several comets had large clouds of hydrogen around them, but also that there were large amounts of interstellar hydrogen near the sun. One sees a maximum in the ecliptic plane. Over 6 months one sees a parallax of  $60^\circ$ , which says that the emitting region is very close. This is consistent with interstellar hydrogen penetrating to within the orbit of Jupiter in the direction of the sun's motion, only 4 AU away. One would expect to see the temperature of the solar wind increase as it interacts with the neutral interstellar gas. The MJS mission may see this heating of the solar wind. The maximum was in the direction of the grand tour mission.

Cosmic rays are truly interstellar. Cosmic rays cannot be detected at earth if their energies are less than a couple hundred Mev.

Trajectories for out of ecliptic missions are being considered. To date we have been restricted to a small portion of the ecliptic plane. Sun spots occur well away from the equator, e.g. at  $45^{\circ}$ . We could use Jupiter assist to get any desired inclination.

#### Possible Out of Ecliptic Missions

Helios C (a few degrees in a direct launch)

Jupiter flyby

Venus flyby (e.g., the Pioneer Venus probe bus could get  $11^{\circ}$  out of the ecliptic)

Electric propulsion

#### Magnetosphere Missions

Mother-daughter (with ESRO)

Injun 6

Atmosphere Explorer

#### Interplanetary/Planetary Missions

Pioneer G 1973

Mariner Venus Mercury 1973

Helios (mostly West Germany)

Mariner Jupiter/Saturn 1977

Pioneer Venus Orbiter (with ESRO) ?

Pioneer H??

## 9.6 PLANETARY EXPLORATION AND THE FUTURE OF MAN

Robert Jastrow (Director, Goddard Institute of Space Studies, New York)

I have prepared some suggestions for thought more philosophical than what we have heard today, but derived from the same body of facts.

The consequences of these developments go beyond the disciplines of biology and geology, and go into cosmology, which includes the entire human species.

In this area there is both an indirect and a direct impact on our future.

The direct input depends on an attempt to read the history of life and draw conclusions which not even one agrees to among life science scholars.

The indirect input involves three specific questions in scientific cosmology, where illumination will have an impact on ourselves in our attitude toward ourselves as physical entities.

In talking to the largest group of people I can reach, one set of questions which continually arises is: what is my relation to the environment (as an assembly of self-replicating molecules), what am I, how did I get here, what is my destiny. It is the central question of science from the layman's point of view.

Physics and astronomy provide a special input. The earth came into existence as a chain of events starting with an explosion forming a cloud of primordial  $H$  and  $H_e$ .

Stellar evolutionists have put together a more complete picture of evolution of the stars, than planetary evolution, or the evolution of life.

We know the events leading to the condensation of the sun and planets 4.5 billion years ago. At this point the astronomers and physicists withdraw and the paleontologists and geologists take over.

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A-249

However the major gap in the story (not in astronomy) is that which begins at the threshold of life. What is the origin of life? the problem of evolution on earth-like planets. Is evolution determinate? Does it follow the same paths on other planets? What is the probability of the appearance of intelligent life on other planets? Is man unique? There are  $10^{20}$  odd planetary systems in the observable universe.

Regarding the first question, the story is well known to a point. The building blocks of life common to all, the 25 amino acids, have all been made in the lab under primitive earth conditions. We assume, and this is pure conjecture, that in the waters of the primitive earth, these molecules collided to form more complex forms.

The smallest known virus (of molecular weight 50,000) is made up of 100 basic molecular building blocks. A strand of mixed DNA and RNA it harks back to what we think formed in the water, free floating strands. Once there was self-replication we have a mechanism for evolution from simple to complex forms.

We understand the beginning quite well, but I feel that my scientific colleagues are a little more dogmatic, and am sympathetic with the creationists in California (we may never fill this gap completely). We are relying on an article of faith when we say this is established.

But the fossil record shows from 3.3 billion years, and for the last 500 million we have a solid pattern of development.

What has this to do with Mars and the exploration of the planets? We have no a priori feeling for the probability of this occurring. We must have a seed of doubt. Is this literally and figuratively a miracle, because it is so improbable?

There are  $10^{10}$  planetary systems in our galaxy. If the probability is as low as 1 in  $10^{20}$  then we are alone in the universe. If 1 in  $10^{10}$  we are alone in the galaxy. But if it is as large as 1 in  $10^6$ , we could then conclude that our galaxy is teeming with life, and about half may have been around longer than we.

The exploration of Mars can answer this. If the exploration of Mars shows primitive molecules or extinct life, this impact would slowly penetrate the idea of man. It will have advanced Copernican and Darwinian evolution significantly; 99.9% of people don't accept the Darwinian revolution. So much for probabilities.

Can we learn anything from Mars regarding the deterministic nature of evolution. Not directly, for the flowering of life of the Cambrian did not occur on Mars, but we may find evidence of a line of evolution that terminated some time ago. We will have circumstantial evidence that evolution is deterministic if governed by natural selection, even though there is no causal chain on the molecular level.

We may then feel that the evolution of intelligence will occur on all planetary systems. When fish left the water, most fish stayed in the water. In the Permian 200 million years ago, a glacier appeared which put a premium on warm-blooded animals. Ten million years ago there was a mild draught in Africa, and the ground apes moved further into the interior, but a few ventured out into the savana, and didn't retreat with the forests. The hunting mode put a high premium on intelligence. The brain doubled in size between 10 million and 2 million years ago, from 450 cc to 900 cc cranial. In the last 2 million years, it exploded and doubled again. The Pleistocene glaciers set in 2 million years ago. The hostile environment was not lethal but stimulating.

Wherever there is a planet with land, and oceans, and internal radiation heating, I think it is a fair conjecture to say that evolution will proceed along the same course, and there will always be a premium on intelligence evolving.

This view is not shared by the most qualified people in the field, Simpson and Dobranski. These two scholars come full circle and come to the same conclusions that the creationists state. They say evolution has many branches, and man is a single twig, and impossible to be duplicated, and to expect humanoids or even intelligences with which we can communicate is out of the question.

But consider the Tasmanian wolf, which is similar outside but different inside; also the dolphin. There is evidence for determinism in evolution with regard to forms.

As an act of faith I am optimistic. With  $10^{20}$  planetary systems I can't feel we are unique. We won't know the answer to these things for some time.

The direct consequences and the most controversial are with regard to man's evolutionary future. Will man continue to evolve? I think one element of the history of life is illuminating in this connection. There are  $10^7$  species of life on this planet. Simpson says almost all of these became extinct. By probability grounds this will be man's fate. A smaller number do not become extinct, they adapt to a niche which does not change (e.g., the oyster). When settled in such a niche it stagnates. This is the fate of the 2nd largest number of species, and is also a candidate for man - a golden age of stagnation in an Aldous Huxley type of world.

There is one last course that may be our lot. At every stage so far one species has found itself mildly challenged, and a fraction of the species have reached out. I think if we live on this planet forever we will exhaust ourselves. Only in planetary exploration is the chance for seeing another and higher level of organization is man's future.

Q - Re the earth's present environmental state.

A - We are in fact living in the economy of a Polynesian paradise.

Generally it has been cooler on earth. The earth warms up slowly and glaciation appears rapidly. In a few generations we are approaching a new glaciation.

## 10. INTERDEPARTMENTAL CORRESPONDENCE

TO: Distribution D  
ORG:  
SUBJECT: SBRC Visit to Discuss  
Orbiter Infrared Radiometer

CC:

DATE: January 5, 1973  
REF. HS507-0368

FROM: L. K. Acheson  
ORG. 40-91-00

BLDG. 376 MAIL STA. 11141  
EXT. 8-1086

On 3 January 1973, A.M. Lauletta, L.K. Acheson, and P.A. Robinson visited Stillman Chase at the Santa Barbara Research Center to discuss characteristics of the infrared radiometer experiment. Following are the significant points which came out in the discussion:

- o Chase's initial concept of this experiment was that it would be essentially the same as the Mariner 2 experiment, i.e. a two-channel radiometer (6.5 to 8.5  $\mu$  and 9.2 to 10.8  $\mu$ ) looking for holes in the cloud top \*. (He wondered why the microwave radiometer had been dropped, since in Mariner 2 the infrared radiometer was mounted on the microwave radiometer and the two were complementary.) The only additional channel he thought might be useful was a broadband channel of 0.3 to 3  $\mu$  for thermal balance studies.
- o Chase felt that the baseline orbit Hughes has selected, i.e. a 24-hour polar orbit with 150 km periapsis at mid latitudes and spin axis normal to the ecliptic was very good for the IR radiometer measurements. He is going to take a look at the design characteristics required if contiguous mapping is to be provided. (The low spin rate of 5 rpm combined with a low periapsis provides a problem in this regard.) He suggested the possibility of using two fixed fields of view with large angular separation relative to the spin axis to obtain better viewing, and of using slits rather than square apertures to optimize dwell time.
- o The primary measurement region of interest is near periapsis. The only reasons for making measurements from far out are: 1) to define the field of view accurately when the planet is small with respect to the field of view, (The wings of the field of view are hard to measure in the laboratory.) 2) to obtain full planet disk measurements.
- o An advantage to having a pointing capability for the radiometer (e.g. by co-mounting with a mechanically scanned radar altimeter) would be the ability to take data at a constant emission angle (elevation angle) with respect to the surface. The resolution at the poles would be increased by a pointing capability. The only other advantage would be that of being able to look at a given point on the clouds at different emission angles.

\* Chase gave us three papers dealing with the Mariner 2 instrument and results on file in the experiment integration office.



- o On Pioneer 10, which carries a similar radiometer to the Mariner 2, a sun pulse is used as a reference and an adjustable gate is opened when one gets to the planet limb (for one second out of 12 seconds). One could also use a limb sensor, but one loses a little of the limb.
- o It is not good to see the sun each spin (as one would with the Pioneer Venus orientation). One might have to blank out the sun. Although the two basic IR channels are solar blind and would not be damaged by the sun, an albedo channel would be wiped out every time it scans the sun.
- o A Mercator projection of the mapping coverage of the radiometer on the planet would be very desirable. Santa Barbara has the capability of generating these. Paul Robinson will follow up on attempting to get such plots.
- o The emphasis of the SSG study on the measurement of the thermal structure of the atmosphere above the clouds was discussed. At first Chase felt that this would require an IR spectrometer such as the 29-pound instrument carried by Mariner 9 to accomplish, but he later suggested that one might do temperature sounding by looking at the edges of the 14 to 16  $\mu$  band with a few discrete filters. Chase is going to look further at this possibility. The weight allotment for the IR radiometer is nine pounds, whereas the basic two-channel instrument would weigh only 4.5 pounds.
- o Regarding alignment and stability requirements, Chase feels that with a field-of-view of the order of a degree it is not critical. With the IR radiometer it is more important to know where on the planet one is looking than to hold to any particular stability.

Some incidental items of interest:

- o Chase has heard that one funding option being considered is to delay the start of Pioneer Venus in order to fund a third Pioneer spacecraft to the outer planets, Pioneer H.
- o Chase gave us copies of the Technical Proposal for the UV Fluorescence experiment for the Probe Bus which Santa Barbara has prepared, with Dr. Robert Young as Principal Investigator, and Dr. Thomas Donahue as Co-Investigator.
- o When Chase heard that the periapsis altitude of the orbiter was now down to 150 km, he felt it would be much better to put the UV Fluorescence experiment on the orbiter than on the probe bus, since the altitude region of interest is about 220 km to 110 km.

L. K. Acheson  
L. K. Acheson

## 11. INTERDEPARTMENTAL CORRESPONDENCE



TO: Distribution D  
ORG:

cc: Customer (3 copies)

DATE: 16 January 1973  
REF. HS507/0383

SUBJECT: JPL Visit to Discuss  
Radio Science Experiments

FROM: L. K. Acheson  
ORG. 40-91

BLDG. 376 MAIL STA. 11141  
EXT. 81086

On 11 January 1973, D. M. Newlands, L. K. Acheson, and P. A. Robinson visited JPL to discuss the Venus Orbiter radar altimeter experiment with Walter E. Brown, Jr., and the radio occultation experiment with A. J. Kliore. It had been suggested by Joel Sperans during his visit to Hughes in December that it would be desirable to talk to Brown and Kliore. (HS 507-0338, 12/11/72)

#### 11.1 Radar Altimeter

Present at the altimeter discussions in addition to Brown were Charles Elachi and Rolando Jordan. Significant points covered were the following:

- Brown's basic approach to the radar altimeter is to use a longer wavelength and a dipole antenna, and impose no constraints on the spacecraft orientation. The wavelength can be as long as 2 meters, but 2 meters to 15 cm is the general area of operation. Brown has looked at the Texas Instrument type approach and decided that this was too ambitious for this type of spacecraft.
- Their technique for measuring altitude is different from most. Range to the first Fresnel zone is used. Venus is relatively smooth, but the technique would still work if it were as rough as the moon. They get a return from the specular point, which is in the Fresnel zone, and use a chirp technique.
- The kind of weight and power Brown talks about is 25 lb, 25 watts, but this may go down when one talks about specifics. A Mariner radar design was about 18 lb, 18 watts and the minimum Venus Orbiter radar is probably in the same category. They crank out about one radar design a week.
- In essence, they use a wide band pulse, and if you look at phase versus frequency of the chirp pulse, the slope of that line is the altitude. This technique has evolved from the use of synthetic aperture techniques for imaging. It requires a stable oscillator and an omnidirectional antenna. The specular echo is so strong there is no problem.
- The only limitation on mounting the dipole is that one doesn't want to spin about the dipole with the null of the dipole pointed straight down. One would probably put up two sets of crossed dipoles for an omnidirectional antenna.

- Their system peters out (0 db gain point) around 4000 km altitude as normally designed. One of the more significant problems with Venus is the noise temperature. In their studies, they always start with an omnidirectional antenna and then decide if they want to provide some directivity to range to a further distance. The narrowest antenna they have come in with is 40 degrees. If one can tell where the vertical is within 20 degrees, then this is OK.
- The opposite philosophy to this is a highly directional beam, but the spacecraft is a long way from home, and if its orientation doesn't hold the experiment is lost. This approach comes from people who want to design a miniature earth radar. The directivity is not needed. It is perhaps a good philosophy to look at, but one should also look at the other philosophy.
- If you use a longer wavelength, you use a larger dipole, which has a larger antenna cross section, and this helps a lot. There is a factor of 100 or higher for 2 m vs 0.2 m. Atmospheric losses don't begin to take a toll until the wavelengths are shorter than 20 cm.
- There will be a contingency pushing for radar profile measurements on the Venus orbiter. There has been a first meeting between Fletcher and the U.S. Geodetic Service regarding requirements for a Venus mapping radar.
- Brown is planning to have a proposal out for a Venus Orbiter radar by the first week in February. At that point in time, they will have a radar design and could talk in detail about design numbers. Their ground rule is to provide minimum impact to the orbiter design. This is an unsolicited proposal. In the February draft will be the results of the USGS study.
- There is some discussion to go to a dedicated radar mission for the orbiter. The reason is that the atmospheric scientists are supposed to get all their answers from the probes, and so the surface scientists get everything they can from the orbiter. This one of the tradeoffs currently being considered by NASA. But for the moment, the ground rule is, don't perturb the orbiter. People are also talking about balloon payloads.
- A range accuracy of about 10 meters below 1000 km will be obtained with a 20-to-25 pound radar at 2 meter wavelength. It is hard to do better because of atmospheric turbulence. A 10  $\mu$  sec chirp pulse would be employed. Power would be about 20 to 25 watts. This assumes a buffer storage sufficient for several pulses, but no storage for imaging.
- This system, although an altimeter, has all the basic ingredients for imaging, if the antenna can look out to the side. If one had room for more storage, then one could get an image of the surface. The storage needed depends on the number of resolution cells you want. For a 10  $\mu$  sec pulse, it might go up by a factor of 6 or 7.

- From USGS, Brown will get how often you want to sample. Ideally, you should have a sample every Fresnel zone. One would need to sample every 3 sec if you were sampling every 30 km.
- The length of the dipole for a 2 meter wavelength would be 1 meter, or 50 cm on each side of the spacecraft. One may want more than two. For the Hughes baseline polar orbit with periapsis at 30°N latitude, one probably wants to tilt the dipole slightly off the spin axis. The problem is to try to minimize the portion of the spin that the null is pointing toward the planet. There is considerable flexibility in mounting the dipole elements; for example, they don't have to be 180 degrees apart. The MJS antenna ended up being part of a rhombic.
- Brown is also interested in a wind drift radar for the large probe. He has just submitted a proposal to Ames entitled "Atmospheric Dynamics of Venus - 1977 Pioneer Venus Probe Mission," and gave us a copy. Again, he uses a broadbeam radar that can be mounted anywhere on the bottom of the probe. The radar is an 18 lb, 13 watt S-band coherent pulse type radar that measures: range, range rate, doppler spectrum, echo amplitude, and echo phase jitter. It utilizes separate transmit and receive antennas and wants as much separation between the two as possible. Measurements start at 72 km and go all the way to the surface with a bit rate of 34 bits/sec. The output of the measurements is: vertical velocity, horizontal velocity, range, and turbulence of the atmosphere or roughness of the surface.

The wind-drift resolution is 0.3 to 0.1 m/sec. Magnitude is measured but not direction. Brown would like to use this radar in conjunction with the DLBI measurements.

## 11.2 Radio Occultation

Following are the significant points that came up in our discussion with Kliore:

- Kliore emphasized that in the preliminary SSG study, he had made it clear that for the propagation experiments one needs two dimensional pointing of the orbiter antenna to follow the refractive bending of the signal. There is a 17 degree refractive deviation in a two-dimensional curve. He complained that the Orbiter SSG contained no occultation scientist, although it had some radar types.

If this two-dimensional capability isn't provided, the occultation experiment is severely degraded, especially the X-band experiment which would give information on the lower clouds. (The degradation is less serious for S-band because the beamwidth is wider.) So in the preliminary SSG study, Kliore had suggested a two-axis steerable antenna. There are other ways of doing it but not on a spinning spacecraft.

- With regard to the orbit desired for the occultation experiment, it is not true that they don't want a polar orbit. The preferred orbit is one that gives a maximum number of occultations and as much latitude coverage as possible. Also, it is advantageous if the occultations do not occur at

apoapsis. A polar orbit gives the maximum latitude coverage, and a 100-day occultation season is quite acceptable. Any highly inclined orbit ( $> 60$  degrees) would be acceptable.

- Kliore said that his co-worker Fjeldbo is looking a little bit at various orbits to see how much one needs to move the antenna. This is an unfunded study which might be finished in the next few weeks. He suggested we call him (Kliore) to get the results. He feels that one would need to track the signal within a degree or so.
- With regard to the question of a possible second occultation frequency other than X-band, Kliore thinks that this would open a whole new can of worms. Although it would be useful to have a lower frequency less susceptible to particle attenuation, the problem is that the DSN is not instrumented for lower frequencies. Kliore was surprised to see the X-band occultation experiment listed as an other candidate instrument, because he feels it doesn't cost much.
- The Mariner Venus Mercury spacecraft has a two degree of freedom antenna, and will provide occultation data on the Venus flyby. This was not done for the radio science, but to provide better data back from Mercury.
- Kliore considers the bistatic radar experiment to be marginal in any case, because of the magnitude of the return, and although he doesn't have any detailed calculations, he feels that with a spinning spacecraft one would have a hard time distinguishing the radar signal from noise. He doesn't think this would be a very useful experiment.
- Kliore has heard all kinds of rumors from NASA that look bad for Pioneer Venus. He certainly hopes that it does go and that it has a two-axis antenna. His only reservation about Pioneer Venus is that the Russians might do it first.

L. K. Acheson  
L. K. Acheson

/nn

## 12. INTERDEPARTMENTAL CORRESPONDENCE

TO: Distribution D  
ORG:

CC:

DATE: 16 January 1973  
REF. HS507/0382SUBJECT: Ames Visit on 1/11/73,  
Magnetometer Study ResultsFROM: A. M. Lauletta, Jr.  
ORG. 44-24BLDG. 376 MAIL STA. 11141  
EXT. 84509

The writer, C. Thorpe and J. Salvatore visited Ames to discuss the results of the magnetometer studies, EX-15. The following personnel from Ames attended the meeting:

J. Sperans  
S. SommerR. Christiansen  
T. Canning

A second meeting was held later in the day with L. Polaski to clarify experiment data rate requirements.

Magnetometer Study Discussion

Chris Thorpe discussed the study approach taken to evaluate magnetic control requirements on the small probes. Ames asked if Hughes felt, for similar conditions, if it would be more expensive to locate the magnetometer on the large probe. Chris said yes it would be, by a considerable amount. Ames agreed with this.

Ames said they thought the 2% of the total program cost for a sophisticated magnetic cleanliness and control program was low. Their estimate was more like 4%. However, it really depended on the total program one was considering.

The experimenters requirements indicated a 1000 gamma background would be satisfactory, but the need to measure to 1 gamma indicated a difficult stability requirement. Chris felt this was not at all practical to achieve; it would be more like 10 gamma.

Ames suggested Hughes provide the costs for accommodating the magnetometer in the small probe considering reasonable stability requirement and the 1000 gamma background as a guide. The stability requirements assessment can get very complex. It was generally agreed that some judgment is required in assessing temperature effects, pressure effects, structural changes, etc., which could change the probe magnetic field.

Ames asked if we had considered locating the magnetometer externally. We said yes, but dismissed it rather quickly due to complexities in probe thermal and structural design to protect it through entry and to the surface.

Ames indicated their assessment of the four recommendations in the study were no to one, two depends on stability, three yes, and four not acceptable.

Chris discussed the probe bus and orbiter studies indicating the final study results of boom size versus cost versus magnetic control program.

Ames thought \$30K was quite low for a 20-foot boom and discussed this area further. They thought it was more like \$100K. Chris explained the cost was obtained verbally from a reputable vendor and that it may have been lower than expected since they were quoting existing design from another program. We should verify this cost estimate for the mid-term review.

Sperans asked for weights of the various booms and deployment mechanisms. We supplied these to him.

Si Sommer mentioned that there could be a problem with probe bus stability, aerodynamically, in the near vicinity of Venus prior to disintegration. We should look into this further.

Jerry Salvatore discussed the control system considerations for various boom lengths deployed and undeployed. He related the differences between our mission and the previous Pioneer class missions. Bob Christiansen asked several questions which Jerry answered. They appeared very interested and took notes during this discussion as well as earlier.

Ames gave their preference of the various alternatives as the short boom (42 inch baseline design) and minimum magnetic cleanliness control (17 gamma at the magnetometer). Sperans verified this approach with an Ames magnetometer expert while we were there.

Ames also suggested we provide the cost for this approach also as a separate item for each mission.

#### General

Ames thought the discussions were quite good and timely since the data provided (we left preliminary stamped copies of the rough draft of the study with them) would aid in the evaluation of the magnetometer experiment currently in process.

Our baseline approaches to accommodate the magnetometer in each payload should include costs.

Ames suggested we include Jerry's discussion on control system consideration in the study. I agreed.

#### Science Payload Data Rate

I discussed the problems associated with the latest probe experiments data rate definitions given to us by Ames. Data rate for probe experiments was specified in bits per second rather than bits per kilometer.

Ames said to use our own judgment on instrument sampling requirements. If we preferred bits per kilometers, we should consider in a general sense that the experiments would require samples based on scale heights and that some instruments would prefer more samples in altitude regions of greater interest. They could not provide this kind of data to us at the present time.

My impression was that we did not have to provide a system capable of the latest data rates given to us. We should make our own judgment on samples per scale height per instrument. There was no clear specific direction given to me regarding this matter.

I don't think Ames will be able to provide such data until experiments have been reviewed and iterated with system design tradeoffs.

  
A. M. Lauletta

/nn





TO: A.M. Lauletta, Jr. CC: Distribution D  
ORG: 44-23-00

DATE: February 1, 1973  
REF. HS507-0404

SUBJECT: Hannes Alfven Lecture on  
the Evolution of the  
Solar System

FROM: L.K. Acheson  
ORG. 40-91-00

BLDG. 376 MAIL STA. 11141  
EXT. 8-1086

The extremely interesting presentation by Mike McElroy at Hughes on 31 January on the reasons for studying Venus, Mars, and Earth together to obtain a better understanding of planetary evolution prompts me to issue these notes on a Sigma Xi lecture given by Nobel Prize winner Hannes Alfven on 18 January at California State University - Northridge on the subject of Evolution of the Solar System.

Professor Alfven is a strong proponent of planetary probes to the asteroids. The National Science Foundation and NASA supported a recent colloquium on Physical Studies of the Minor Planets at Kitt Peak, which Professor Alfven helped organize. He favors a mission to the Eros asteroid (3000 meter diameter) midway in size between planets and meteorites (a 20 order of magnitude mass gap).

*L.K. Acheson*

L. K. Acheson

Attachment - 7 pp.

LKA:vv

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## EVOLUTION OF THE SOLAR SYSTEM

Hannes Alfven

(Royal Institute of Technology, Stockholm)

The evolution of the solar system is a classical problem. Kant and Laplace introduced it in the scientific era but it was already mentioned in earlier religious writing, because this is one of the central problems man asks himself. The question has been and still is controversial, how the solar system originated and how it evolved.

No wonder. When one tries to reconstruct events of five billion years ago, one asks if it is possible to reconstruct them. Do we have enough data to reconstruct. For example, the origin of life on earth and the whole evolution leading to the cell is something we have very little hope of ever solving. Whether the problem of the solar system is a similar kind is one to be discussed. To do this we have first to look at astrophysics.

Many people believe astrophysics is a field in which one can discover new laws of physics. It is a large framework with bold hypotheses, and we are not sure how many of these will really survive. It is important to reduce the speculative element in astrophysics. The problem is how this is to be done.

Astrophysics is primarily an application of what is known in the laboratory. The finite velocity of light, established 300 years ago, is the only law of physics discovered by astrophysics. The probability of doing so (discovering a law) is very small. Laboratory experiments can tell us much more, generally. Therefore a new field in astrophysics can't be treated in a scientific way until laboratory physics has progressed to a certain stage. An example is how the stars produce their energy. In the 19th century there were many speculations, and it became a more and more difficult problem when man realized the age of the sun. It was impossible for anyone to find out how the energy was produced before nuclear physics was born.

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A-265

The origins of the solar system won't be solved until a number of fields of physics and chemistry have reached a certain stage. There has been a rapid development in a number of such fields, and there is a better background for approaching the problem than Kant and Laplace had, or even than von Weizacker had a few decades ago. Since then we have realized the importance of electromagnetic forces to astrophysics. Also celestial mechanics has developed a new boost from the calculation of spacecraft orbits and the use of computers. Hypervelocity collisions is a growing field, e.g. collisions in the asteroid belt. There are enormously important chemistry and geology aspects which I know very little about: petrology, radioactive tracing methods. For example one can get an entire history from one grain of the moon. These radioactive methods give enormous information about earlier times.

Of course this is all coupled with space research. In the last five or ten or twenty years there is so much more information that one can approach the problem in a much better way now than a short time ago. Much of this is due to space research, and one of NASA's stated aims is to contribute to understanding the origin and evolution of the solar system. This is one of three problems: the problem of the origin of life; the problem of the origin and evolution of the universe, (focused on by large telescopes and other new techniques that can be used above the atmosphere); and the origin and evolution of the solar system. The latter is a special situation, because by space technology one can approach the problem in a different way, a much less speculative way.

With all respect for optical measurements, there is no comparison to getting a specimen of what the bodies consist of and of making in situ measurements of magnetospheres. Fifty years ago the earth was supposed to be located in completely void space. Now if we look at a picture of the magnetosphere we see a highly complicated structure in space, with currents of magnetic fields and charged particles moving in different directions. Enormous information was gained by the Apollo mission to the near moon; material we need to understand the structure of our environment and how it has changed in time.

Then comes the problem of how, of what approach, to try to reconstruct the origin of the solar system. The classical way is the same as Kant/Laplace/Weizacker. One tries a hypothesis as to the state of the sun and surroundings of the sun when the sun and planetary system were formed. Kant suggested an interplanetary cloud that contracted and formed the sun, but some dust contracted and formed rings that later formed planets. It sounds rather attractive, particularly after having heard it for 200 years.

But what support do we really have for this view? There are severe difficulties with the formation by contraction, and there is no observational evidence that this was the process. If one asks if the sun could have been formed in a different way, the answer is yes, for example by accretion. There are no solid arguments. If you make a hypothesis, no matter how attractive, you are on loose grounds.

It is much more attractive to go the other way, to start from the present state of the solar system, and try to reconstruct how it evolved. What was it like a thousand years ago, a million, a billion years ago? We can calculate the position of the planets back a thousand years, more difficultly a hundred thousand years, or a million years. One finds certain periodic changes. Other phenomena are also at work. In the moon system, the tidal action on the earth makes the moon more distant. If we extrapolate back, the moon was much closer to the earth, and originally an independent planet that was captured by earth.

If we go back in time, nothing much has happened to the planets for a few billion years. (But there was a very dramatic period some four billion years ago when the solar system attained its present situation.) The surfaces of celestial bodies have changed slightly. But in the asteroidal regions there are large numbers of bodies, and they occasionally collide. This region is certainly in a state of development. Also there are more rapidly changing elements, the comets. When comets come back after a number of years they are changed. The smaller the body, the more likely it is to be changed. Large bodies such as Jupiter and the earth are decoupled from the surroundings to a much higher extent. The approach is to go backward in time; the further back one goes, the less reliable are the results.

There is another important point. Suppose we find a theory of the origin of the solar system that seems attractive. How could we check that. We have only one specimen of the solar system. It is likely that many stars have similar solar systems but the probability of studying them is very very small. Even to see a large body like Jupiter in the neighborhood of a neighboring star is beyond technical means. There have been some reports of planets by perturbation calculations.

However the sun is surrounded by a number of planets, and some of these have a number of satellites around them. If you look at these, you get the impression that they are planetary systems in miniature, and if you look at them in more detail, you are impressed at the high degree of similarity. The orbits are more circular than the planetary orbits. The inclination of the orbits relative to the ecliptic plane is very small, especially in the Uranian system. They are planetary systems made with higher precision.

Suppose there is a process by which any standard body produces secondary bodies, and we have a process to explain this. Then we have four specimens in our close neighborhood: the planets around the sun, the Jupiter system, the Saturn system, and the Uranus system.

If we start from the assumption that one process has formed all these bodies, then we can rule out a number of hypotheses. It has been claimed that the sun was once a nova or supernova and ejected the planets, but no one claims Uranus was a nova. Similarly, the sun may have collided with another star, but such processes can be ruled out. This approach that we want a similar process for all four systems is very powerful, because so many processes seem to work well for one but not for all.

The approach one gets in this way as most interesting is that of accretion from smaller bodies; i.e. the matter we now find in Jupiter and the earth was once a swarm of small bodies that has accreted. Figure 1 shows the postulated sequence.

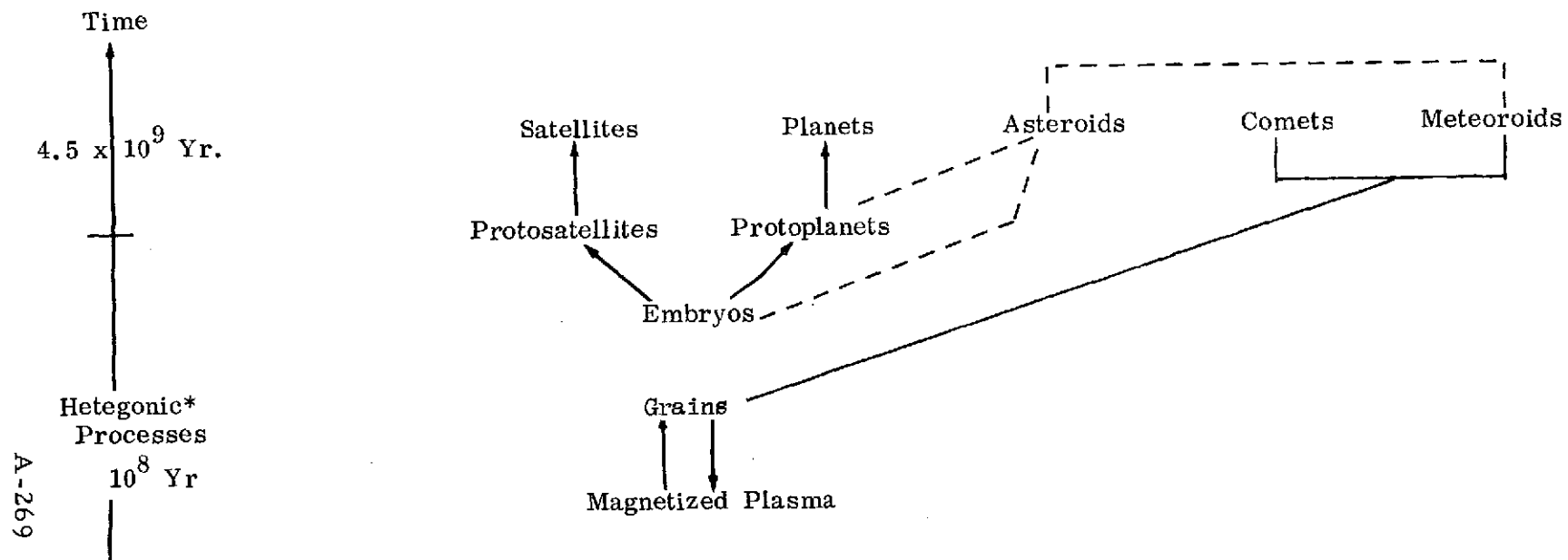


FIGURE 1. Solar System Evolution

\*Companion Forming

We now come to the question of the asteroids. What are they? The earlier theory was that they were fragments of a planet, but it is quite probable that the asteroids are a specimen of the embryos state which is evolving at a slower rate. Similarly meteoroids have properties similar to grains. Comets and meteoroids are known to be closely associated. Usually it is said that meteoroids are fragments of comets, but if we go to the theory we ask if it is possible that comets could have been formed out of meteoroids.

Now we come to the question of the physics. The accretion process has not been studied in detail. Asteroids are supposed to have been derived from an exploded planet, but if particles collide inelastically they do not spread more; rather after a collision they move in more similar orbits, i.e. the orbital elements become more similar. A theoretical plasma physics formulation has been applied to the problem and we have found a negative diffusion coefficient for a number of particles orbiting the sun. It is quite possible then that comets may be formed out of meteoroid streams. This doesn't mean that there can't have been other processes too. But the study of jet streams and small bodies orbiting the solar system is one of the important problems.

The solar system has come into existence by a number of very complicated processes, not just one simple theory. We need hundreds of Ph.D. doctoral dissertations in many different fields. We must try to form a new field of science, by drawing from a large number of sciences.

Question - Regarding the constant isotopic ratio over the surface of the earth, do we have any explanation for this?

Answer - This should mean we had a rather thorough mixing of the material out of which the earth was formed.

Question - Would this apply to other parts of the solar system?

Answer - The early belief was that all parts of the solar system were made of the same type of matter, but this is certainly not true. Uranus and Neptune have the same size but very different densities. The chemical composition of heavy bodies is a function of several mechanisms: the plasma process, condensation of grains, accretion process, geophysical differentiation.

Question - The most astounding discovery of the last decade is the reversals of the magnetic field of the earth. Does this play any part in solar system evolution?

Answer - The earth's magnetic field is produced by hydromagnetic forces in the core. A number of other bodies have a magnetic field. For understanding the processes of the solar system, electromagnetic fields are essential, for example in the Uranus system hydromagnetic transfer from the central body is needed. Only bodies having a magnetic field can generate secondary bodies. But it doesn't matter which sign they have.

Question - Regarding the negative diffusion coefficient, it seems to be a statistical question since collisions can be completely elastic or inelastic.

Answer - The gravitational contraction of these bodies is negligible. When they collide, they may fragment. The problem is difficult because we don't have the composition. One must have a certain degree of inelasticity, otherwise the system would spread. But we don't know much about the structure of these bodies. We can't tell from meteoroids. Most are destroyed at high altitudes. We get only a rare specimen, those with enough tensile strength to survive to the ground. Many people believe that most objects have a very low density; they are fluffy bodies. It is more like a collision between two cotton balls than two marbles. We are trying to persuade NASA to go ahead with planetary probes to the asteroids. NASA has said its highest priority is to understand the evolution of the solar system, and asteroid probes should have a high priority. They seem to have accepted this.

Question - How did you decide that the plasma process is basic?

Answer - We begin from today and go back in time. The picture is that around a primary body like Jupiter there is a region full of plasma.

Question - Some believe that the moon was one of the original protoplanets and not a broken fragment.

Answer - It is very difficult to destroy a planet.





TO: Distribution D  
ORG:

CC:

DATE: February 7, 1973  
REF. HS507-0413

SUBJECT: Pioneer Venus Science  
Briefing by M.B. McElroy

FROM: L. K. Acheson  
ORG. 40-91

BLDG. 376  
EXT. 8-1086 MAIL STA. 11141

On 31 January 1973, science consultant Mike McElroy gave a science briefing at Hughes to help increase the "science sensitivity" of the Hughes Pioneer Venus project members who will be briefing NASA/Ames. Results of very recent research were reported. Attached is a write-up of the presentation.

*L K Acheson*

L. K. Acheson

Attachment: 10 pp.

LKA:vv

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## PIONEER VENUS SCIENCE BRIEFING

M.B. McELROY

I will try to give you the things that turn me on about Venus exploration. Venus is a planet that is telling us a part of the story of the solar system. We must see how Earth, Venus, and Mars compare. Two great goals of the planetary program are to determine the origin and evolution of the solar system, and the origin and evolution of life. Some of us are beginning to think this is possible.

Mariner 9 will tell us something about the evolution of the solar system. Earth and Venus and Mars have a common history. All of the planets formed out of a gas or nebula. The difference between the planets is due to a difference in temperature of formation. The assumption is that Venus was formed without any water. Another feature of the models is that toward the center of the nebula one expects the gas to be turbulent, so the inner solar planets should not have an atmosphere, while in the outer solar system everything can stick.

Let's make the assumption that hydrogen is retained as water on earth, and as ice on Mars. but that there is no hydrogen at Venus. This is the John Lewis view of the formation of Venus.

How do planets get an atmosphere. The idea, elaborated over the last 35 years, is that the air comes out slowly from the crust over five billion years, and is a secondary atmosphere.

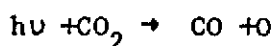
On earth there are 45 molecules of  $H_2O$  outgassed for one of  $CO_2$  and 0.03 of  $N_2$ . The water goes into the ocean. If it went into the atmosphere, earth would have 100 atmospheres of pressure. The  $CO_2$  is in equilibrium with the ocean and condenses out as calcium carbonate. This precipitation process is very specific and requires water. If the  $CO_2$  stayed in the atmosphere there would be 33 or 40 atmospheres pressure.

On Venus there is no water because of the temperature and the  $\text{CO}_2$  stays in the atmosphere. Mars has water present as ice but this is not any good to precipitate  $\text{CO}_2$ , so it stays in the atmosphere. The pressure on Venus is 100 atmospheres, on earth one atmosphere, and on Mars  $10^{-2}$  atmospheres. The simple explanation is that Mars has outgassed less. Venus is well on its way and has pumped out most of its gases. Mars has just started. Murray from Mariner 9 argues that the Mars atmosphere is very recent.

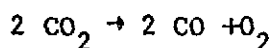
There is another part of the story that interests people, particularly geologists. The present view of the earth is that a recycling process takes place. Outgassing occurs from the "ring of fire" volcanos, and goes back into the ocean. Under the plate tectonic theory, the ocean bed spreads and goes back into the interior under the continents.

Masursky says that one can't get a complete picture of this from the earth. The early history of continent forming is absent. Mars is telling a little about the beginning. Venus is interesting from the point of view of understanding how these processes get started. It is a completely new ball game at high temperatures. Masursky has come to the view that the most important thing the U.S. can do is an orbiter of Venus with a radar altimeter to see if continents are present. He would like to look for caldera or rings of volcanos. One would need a resolution of a few km at Venus, which is comparable to the resolution from earth at the subearth point. This interest has arisen in the last year.

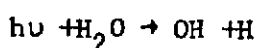
Another very interesting part of the story is the stability of the  $\text{CO}_2$ . If you irradiate  $\text{CO}_2$  in the lab with UV it decomposes:



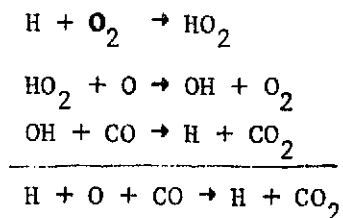
and it is extremely difficult to put back together again. The atomic oxygen tends to form  $\text{O}_2$ .



For Mars what we think is happening is that the atmosphere is held stable because of small amounts of water:



These catalyze the combination of CO and O

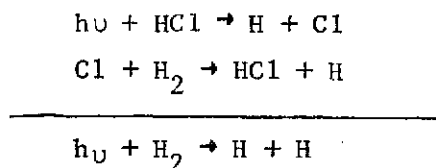


The mixing ratio of hydrogen on Mars is one part in  $10^{11}$  (H/CO<sub>2</sub>), but this is sufficient. This says that the atmosphere is controlled by a very small amount of water. In 10,000 years all of the CO<sub>2</sub> would change to CO and O<sub>2</sub> if no water were present. The H atoms and O atoms escape to the interplanetary medium as H<sub>2</sub>O is continually emerging; otherwise ice would cover the planet to a depth of ten meters. Hydrogen is also escaping from earth, but at a rate of 1/10 that of Mars.

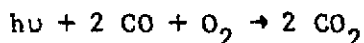
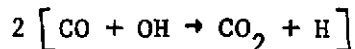
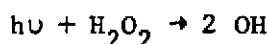
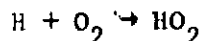
Turning to Venus, what is going on in Venus? If you look at the literature, no one knows. A goal is to determine the composition of the atmosphere sufficiently well to provide a basis for theories.

Our theory is that it depends on the existence of HCl, which is present to one part in  $10^8$  as determined by IR spectroscopy from earth. The stability story goes something like this. UV penetrates to one m bar altitude and dissociates CO<sub>2</sub> into CO and O<sub>2</sub>. But we know that Venus has extremely small amounts of CO (one part in  $10^4$ ) and O<sub>2</sub> (less than one part in  $10^6$ ). Our explanation is that CO and O<sub>2</sub> diffuse downward and then are catalytically combined.

HCl dissociates at a longer wavelength, which penetrates more deeply; also the solar spectrum is getting more intense.



Thus the dissociation of H<sub>2</sub> is catalyzed by HCl. Then one has:



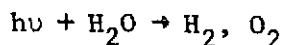
An interesting thing about hydrogen peroxide is that you do form quite a lot. It would be possible for it to condense and it could form a cleaner fluid haze. There is a lot of evidence that the Venus atmosphere above the clouds is smoggy.

Noting that hydrogen is crucially important in stabilizing the  $CO_2$ , we now have to worry about where the hydrogen comes from. It looks as though it all came in from the solar wind. If one asks how much you need to provide the water in the Venus atmosphere, it would require one percent of the solar wind over geologic times.

So we are beginning to argue that the solar wind is the reason for the stability of the  $CO_2$ . How the hydrogen gets into the atmosphere is a very complicated flow problem that the Venus orbiter will try to address. Some atomic oxygen in the atmosphere may be poking outward and the solar wind collides with it, with the charge transferring from the hydrogen to the oxygen, so that the hydrogen can then enter the atmosphere.



If we now translate this back to earth, what was the earth like before life. The big difference life makes is  $O_2$  from photosynthesis. So the earth before life is the same as today with no  $O_2$  (N + a small amount of water + a trace of  $CO_2$ ). Now we think we are able to say something about this. The earth has more water than the other planets.



In 10 to 100 thousand years you begin to build up  $H_2$  and  $O_2$  concentrations that would be dangerous, and could explode. This suggests the big bang theory for the formation of life on earth. After the explosion there would be fragments of many different kinds of molecules floating around which could begin to combine.

The way people usually assume life began on earth is that the atmosphere was initially a reducing atmosphere (hydrogen, ammonia, methane) like Jupiter, but evidence for this is very shaky.

Life has completely wiped out the story of life on earth. We must go to other planets. We can only get earth by looking at all the separate pieces of the solar system. Mars and Venus are essential in understanding the earth. Here I object to the statement that planetary research is not fundamental research.

Another area of interest is meteorology. We can write down fluid mechanics equations to describe the atmosphere, but these equations may not have a unique solution, even if we could specify the initial conditions exactly. In the present state of art, you can't handle them analytically, you have a set of difference equations. If you put these into a computer program, you can get a good forecast for a few days.

Meteorology is concerned with two things: weather prediction - will it rain in L.A. tomorrow; climatology - average weather over long time intervals. For climatology we have no experimental system. We can derive theories but can't test them; we always try to retroactively find out what happened. Climatology is in a bad way. We are trying to push the fluid dynamics equations to better understanding, but computers will never solve this. We are trying to develop general concepts based on fluid mechanics, to see how one can bypass details, bypass the weather, to get long range statistics. Good progress is being made, but we must be able to test theories, and have climates on other planets which can be used. The parameters are conveniently different.

Comparative meteorology of planets is beginning to become very important. I made a briefing to the director of NOAA a month ago and this has resulted in his sending a letter to Fletcher saying that Pioneer Venus is important in advancing meteorology on earth.

Venus involves a meteorology in which Coriolis forces are not important. On earth these are important at high altitudes, but not at the equator. No one was interested in the equator until about a year ago. Venus is a tropical meteorology with complications.

The big question is why is Venus hot. It is a fact that Venus receives less energy from the sun than earth (because its albedo is so much higher), but its temperature is three times higher. Why? We don't know.

There are two major candidate theories, both of which have problems:

1) The greenhouse model - Visible sunlight penetrates to the surface where heat is absorbed and can't radiate out. You can wave your hands and make things happen to earth that are frightening. Earth has a 20 or 30 degree greenhouse effect due to water vapor. If you increase the level of atmospheric pollution, then the greenhouse effect increases, this increases the surface temperature and increases the evaporation of water vapor from the ocean, and so one gets a runaway greenhouse effect so that the temperature rises to the temperature of Venus. Or if the earth were just a little closer to the sun it would also get a runaway greenhouse effect. The fact is that the earth is getting warmer over the last few years.

The difficulty with the greenhouse model is that it is very hard to find materials that transmit visible and blackout IR radiation. No one has been able to explain a temperature of higher than 400-450° by this theory in detail. I tend not to believe this is the explanation. But the recent Soviet discovery that visual radiation reaches the surface means that part of the greenhouse process is verified. One serious problem with Venus models is to explain why there is so little difference in the day side and night side temperature (actually the night side is slightly higher).

A second approach is the Goody and Robinson model which assumes absorption occurs at the top of the atmosphere and a circulation pattern is set up, called Hadley circulation. The atmosphere gets hot at the bottom just due to adiabatic motion - heating due to compression. But the observed fact about Venus is that the surface of the planet is rotating very slowly with a day of 240 days, while the top of the atmosphere is whizzing around with an apparent day of 4 days (100 m/sec)

There have been attempts to explain this as a non-linear phenomena, associated with the sun moving with respect to the atmosphere. The effect has been observed in the lab. The earth's outer atmosphere is super rotating also about 30 percent faster than the earth. When one looks at the numerics of deep circulation (Charney has modeled it), assuming inputs and then integrating for a time until one gets garbage, there is no known numerical technique to get a steady state solution.

Terrestrial meteorology is fouled up by rain and water evaporation. But Venus doesn't have any water and the fluid mechanics may be more viable.

Question - What have we learned from the Russians?

Answer - This question keeps coming up. The SSG group went back to see which of the original objectives have been answered by the Soviets, and the answer was almost none.

The Soviet space program is very highly classified. Military and scientific space are synonymous. The scientific direction in the space program seems minimal. Tom Donahue says you shouldn't be surprised at the lack of Soviet scientific data on Venus. The Soviets have told us nothing about the atmosphere of the earth.

The emphasis in the Soviet program is to be first, and not do in-depth science studies. The other thing they do is build a basic spacecraft, and 5, 6 or 7 copies of it, and pick a science payload to fly at each opportunity. They didn't change the basic Venera payload during the entire series.



At the moment they are retrenching on Venus, and going for the next series. The Soviets were content to discover that the temperature is 750°; our goal is to discover why the surface temperature is 750°.

Question - Four probes doesn't seem enough to determine the atmospheric circulation.

Answer - True. First we want to know the composition of the atmosphere; then where the clouds are. The mass spectrometer is not so much to determine the composition of the atmosphere but of the clouds. As to why there are three probes, we would like to get coverage from Nimbus, but it is more complicated on Venus. Clouds don't permit observation of dynamics. There is not one cloud deck expected for Venus but 6 or 8, according to simple theory, the Lewis models. There are important traces of Hg in the atmosphere, which condense at 450 degrees, so one expects a dense cloud of Hg there, and above this HgCl. There is some indirect support for this. There is a temperature dip at 40 km which is correlated with Mariner absorption measurements, and correlated with Lewis' dense Hg cloud.

Once you define the optical properties, then you are ready to do serious meteorology. The three small probes may get a little additional information.

Question - Why have any small probes?

Answer - Some models make particular assumptions about rising and descending atmospheric motions. If we could hit that kind of thing it would be very nice. One hopes to see a significant dissymmetry, and if all are the same, then this is a constraint to which the models must conform.

Question - The small probes are a luxury in a way.

Answer - I agree. The predominant science return is from the large probe.

Question - Doesn't this mean that one should consider carrying fewer probes if weight is a problem?

Answer - But one could eliminate less important instruments on the large probe, and also relax the requirement on the miniprobes to reach the surface. There are lots of options, e.g. remove the magnetometer on the small probes. Temperature, pressure, and any kind of tracking information on the small probes

are more important than the shock layer radiometer, or the aureole detector, or the hygrometer.

Question - What about the probe bus experiments?

Answer - In terms of how it came into being, if you have a probe, then you must have a probe bus, and you don't want to waste it, so you put in elementary particle and fields things, target the bus and do measurements of the upper atmosphere with mass spectrometers, and a Langmuir probe. UV Fluorescence was added as a supplement to the mass spectrometer. But the upper atmosphere is lower priority in the beginning because it is well done from the orbiter.

Question - What measurements are needed to test your new theory of upper atmosphere chemistry?

Answer - It is important to make measurements to verify the chemical theory. One can't see trace constituents with the mass spectrometer, but one can measure the hydrogen to deuterium ratio, and this ratio will determine the origin of the planetary hydrogen. The other way the upper atmosphere experiments are important is in understanding the dynamics of the upper atmosphere, so the mass spectrometer will look at helium and argon as a function of altitude. There will be an exponential increase in science information as one penetrates to the lower atmosphere. You should measure a region on a per molecule basis rather than a per kilometer basis.

Question - You can get the same data from the end of the orbiter mission by letting it decay.

Answer - You have the old problem that people don't want to wait. I would not want to wait for the orbiter. The best thing to do, if you have to back off on weight is first don't insist that the small probes go deep. Retain the bus science, it is an important part of the story. Before dropping the bus science, I would cut back on some of the lower priority large probe science.

Question - Isn't seismic data desired on the small probe?

Answer - I believe this is not an important part of this mission.

Question - What is the reason for the magnetometer?

Answer - There are three types of scientists: theorists, space experimenters, and particles and fields people. The story is that one would like to know what the magnetic fields of the planet are. They tell you something about the interior of Venus. The problem is that the particles and fields people, if you let them on, will gobble up the spacecraft. They are not interested in why things happen, just in making measurements.

Question - I would like to go back to the early life on earth step and the build-up of hydrogen.

Answer - Once you have enough oxygen to form ozone, it is dissociated by sunlight, and then can break down  $H_2$ . Molecular hydrogen has a lifetime of two years on earth. It is a photodecay product of methane, which here is biological in origin.

Question - Is there a lower limit to the six or eight cloud layers?

Answer - No. There is no reason why clouds couldn't be down to very low altitudes. The Lewis models are interesting but not necessarily valid. They are based on a lot of unproven assumptions. The Lewis model would say that earth's atmosphere doesn't have any oxygen, or any methane.

Question - Is there anything on the payload that would give a key to volcanic activity?

Answer - Trace gases would give a direct indication of this. The mass spectrometer would handle this. The Russians didn't see volcanic activity, they only made observations of what appeared to be volcanic type rocks.

Question - What about the Russian measurements of composition?

Answer - An example of how bad the Soviets are is their report of atmospheric constituents. They haven't flown a mass spectrometer, they took along high school chemistry litmus paper, and reported one percent water, but this is wrong. It is not consistent with radio spectrography. My suspicion is that the experiment is sensitive to the presence of HCl. Then they also said from Venera 4 that the atmosphere had 1% molecular oxygen, but ground based spectroscopy shows 1 part in  $10^6$ . The Russians have never flown a mass spectrometer in the earth's atmosphere.

15.0 INTERDEPARTMENTAL CORRESPONDENCE

TO: Distribution D  
ORG:

CC:

DATE: 20 February 1973  
REF. HS507/0433

SUBJECT: Meeting with Von Eshleman  
on Radio Occultation

FROM: L. K. Acheson  
ORG.

BLDG. 376 MAIL STA. 11141  
EXT. 81086

On 9 February, a visit was made to Von R. Eshleman at Stanford to discuss the radio occultation experiment and requirements it might put on the spacecraft communications antenna.

Persons present were:

Stanford: Von Eshleman, G. L. Tyler

Hughes: D. Newlands, L. Acheson, A. Parks, T. Straus

The following information was obtained:

Mariner Venus Mercury will have a dual frequency occultation experiment. Its antenna is articulated 360-degrees in the ecliptic and  $\pm 10$  degrees out of the ecliptic. The two-axis antenna is provided primarily to allow 117 kbits to be transmitted from Mercury at S band.

Tyler feels that the Venus data at S- and X-band from MVM will really point up the power of this method and that after this, there will be much more push for dual frequency occultation.

Eshleman's view is that they are sending three small probes to Venus to measure nothing but pressure and temperature, whereas he can measure this over the entire planet down to 7 km with the S- and X-band capability. Eshleman has been waging a 10-year battle about doing this.

MJS will use a Viking S-band transmitter for cruise science data plus backup in case of thunderstorms for the primary X-band system.

X-band is interesting at Venus because of the atmospheric absorption. The effect of a dispersive medium is greater at lower frequencies, but the precision of measuring phase change is now so good that meaningful measurements can be made at S- and X-bands. S- and L- bands do not seem practical. S- and X-bands work only because there has been a great deal of work making differential phase measurements through the DSN. This would have to be solved all over again for Arecibo.

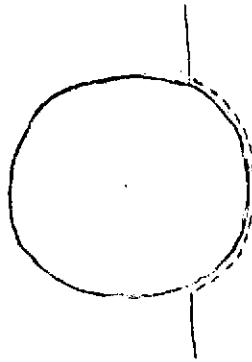
There is a requirement for a very high S/N, i. e., 30 or 40, to make very fine dispersion measurements, i. e., to 1 degree.

The arguments for a dual frequency altimeter are not as cogent as for occultation but they are good ones.

Regarding polarization, the only reason for wanting linear is for the solar occultation that occurs at superior conjunction, but it is indifferent at the planet. For a bistatic application, either linear or circular can be used; Tyler is tending toward favoring circular.

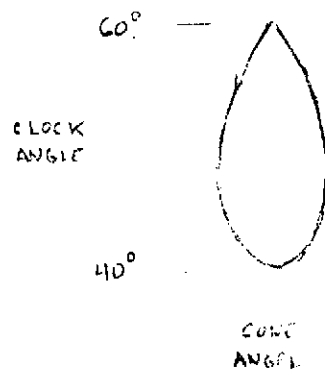
The beauty of the orbiter is that it can time share. You build one system that can do different things at different times.

Having the inclination exactly 90 degrees helps quite a lot. The desired programming of the spacecraft antenna during occultation is shown below.



During the entire period of the occultation, it is desirable to keep the antenna pointing at the planet limb, even though during a portion of the passage the signal may fall below the detectable level. For occultations near the rim, the signal will be detectable during the entire occultation.

For the MVM encounter, the path of the virtual earth is shown below (from a Fjælbo JPL memo dated 11 December 1970).



Meeting with Von Eshleman  
on Radio Occultation

Ref: H5507/0433  
Page: 3

From Mariner 5, it was found that the absorption did not change much with altitude over the region of 35 to 50 km, as observed at high frequencies. This was very surprising. If there were a condensate present, the absorption would vary exponentially.

Von Eshleman thinks the DLBI experiment of Shapiro is a good one to see how far one can push the technique. It may not measure winds but the results would be interesting.

L. K. Acheson  
L. K. Acheson

LKA/nn



TO: Distribution C  
ORG:  
SUBJECT: 13 February Science  
Briefing at NASA/ARC

cc:

DATE: 21 February 1973  
REF. HS507/0434

FROM: L. K. Acheson/  
ORG. A. M. Lauletta

BLDG. 376 MAIL STA. 11141  
EXT. 81086/84509

## Persons present:

NASA/ARC: J. Sperans, L. Polaski, L. Colin,  
S. Sommers, T. Canning

Hughes: A. Lauletta, L. Acheson, C. Thorpe

On 13 and 14 February, NASA/ARC gave separate science briefings to Hughes and TRW/Martin to provide the latest data on the multiprobe mission payload, including both the nominal payload and other candidate instruments for which they have received proposals. In several cases, alternate instruments for a given experiment were shown, and NASA seemed interested in getting some reactions from the spacecraft contractors regarding possible experiment integration problems associated with the different approaches.

Attached is the experiment data package handed out at the meeting. The entire day (13 February for Hughes) was spent in systematically going through this material with NASA providing additional commentary on each instrument and sometimes showing drawings of the instruments (which they declined to make available because some of this information is somewhat sensitive prior to a final decision between various experimenter proposals).

Following the charts is a brief summary of comments made on each experiment. It was emphasized that NASA did not intend that Hughes change anything for the design review, or even necessarily afterward, but that if the new information made it possible to overcome some difficult design problems, it could be used. It was also emphasized that this information should be treated in a sensitive manner, since the procedure for experiments selection is still under way and competitive. There are good possibilities among the "other candidate instruments," as well as instruments not previously listed of being selected as candidate experiments.

Ames noted they were very interested in individual instrument effects and were looking forward to the 26 February review for additional information. It appeared that experiment selection has been delayed thereby allowing Ames more time before their presentation to NASA Headquarters.

L. K. Acheson  
L. K. Acheson

A-289

A. M. Lauletta  
A. M. Lauletta

Attachments

600-000000

## LARGE PROBE - NOMINAL PAYLOAD

Temperature Gauge

It is planned not to fly redundant sensors, hence the reduction in weight, size, and power.

Pressure Gauge

The same is true for pressure.

Accelerometers

There is no change in the package. Regarding alignment accuracies, the real need for precision is in knowing where this is after it is in place. The tolerance is comparable to the accuracy with which the c. g. is known (e. g., 0.01 inch). The alignment of the accelerometers relative to one another is much more important, but this is internal to the package. However, it is important to try to keep the accelerometers on the spin axis.

The seismic mode is automatically switched on when the probe hits the surface. It is not a primary mode; it is sort of an underground mode, and we don't want to advertise it. One could revert to the entry mode at impact, but we show 40 bps rather than 80 because we felt one might want to have pressure and temperature on after impact also.

There is a possibility that the accelerometer package will shrink if the Bell instrument comes along as planned. It is to be an on-shelf instrument in one year. The weight might then go down from 2.5 pounds to 1.5 pound.

IR Radiometer

This instrument is looking downward at clouds as well as the surface, and what it learns on the way down is as useful as what it learns near the surface.

Power, weight, and volume are slightly reduced.

A power of  $\pm 15$  vdc is shown because we wanted to show what the scientists are asking for. The fact that the accelerometers are listed at 28 vdc doesn't mean the experiment couldn't use a different value.

In this instrument, we are not specially concerned with keeping the window clean. Other instruments are much more critical.

Solar Radiometer

Four versions of this instrument are in a horse race. The first two are quite similar, and use four telescopes to measure the solar flux. Both ignore the problem of the parachute. (Canning observed that the great bulk of the region studied by this instrument is after the parachute is dropped off, but Sperans felt that if they don't fly the aureole detector, then the higher altitude observations with this instrument become more important.)



The second two are similar in being essentially solid bodies with only a single opening on the side. The first of these utilizes a bundle of four light pipes which come out in one tube; the second uses a mirror to obtain upward and downward fields of view alternately. There are two problems with light pipes: transmission at particular wavelengths, and the question of whether a few failures in a bundle would cause a problem. They do provide quite a bit of flexibility for mounting. Sperans feels it is worth looking at light pipes generally. Some other instruments could go to this. The second experiment group (D) came out against light pipes because of calibration problems with wide bands they were using.

### Nephelometer

Again, there are several instruments to be considered. The first two are similar. (A) is the one described earlier (for the small probe). There will be a tendency for it to grow in size a little. It has a choice of one or two windows. (B) doesn't exist yet as hardware; (A) has been breadboarded. (C) is similar to (A) but requires two 1-inch diameter windows. This is a bigger instrument but offers the possibility of ranging.

### Cloud Particle Size Analyzer

This is considered to be a fourth member of the nephelometer family. It is a much bigger instrument. Canning is interested in the trim attitude that this instrument might produce aerodynamically. Alignment accuracy has not yet been specified.

### Aureole/Extinction Photometer

This was proposed as a portion of the solar radiometer instrument (A). It has been broken out as a separate instrument here, with numbers assigned specifically to it. It has a 5-degree slit to allow for wobble. It would be very restrictive on probe targeting.

### Shock Layer Radiometer

It was stated that this instrument is unchanged, but the volume listed here is slightly larger than that given before (30 in. vs 26.5 in.). If a clean window could be guaranteed, then the requirement for calibration during cruise would go away.

### Mass Spectrometer

The mass spectrometer numbers provided earlier by NASA represented a composite of the two instruments shown here, and did not represent a real instrument. (A) makes continuous measurements from about 70 km to 10 km. The last 6 km is spent reading out data from an Isotope Ratio Measurement Cell analysis. An 80-minute descent was assumed by this experimenter. The inlet is located 75 degrees from the apex of the

probe, and includes provision for heating (5 of the 12 watts is for heating). (B) takes ten discrete samples from an altitude of 59 km to the surface (to reduce the problem of pressure reduction by one order of magnitude). Its inlet is 30 degrees off the apex. It has a higher mass range and an adaptive scan, never going through a full scan. It has one order of magnitude less sensitivity than (A). Heating is required all the way through the ion source. The experimenter's estimate is 10 watts for heating, but NASA/Ames estimates it will be twice this much. A 60-minute measurement profile has been laid out. A faster descent hurts this instrument because it either limits the number of samples or requires a bigger ion pump. However, Sperans feels that dropping from 10 to 8 samples wouldn't be critical. Peak power is 33 watts during the 48 second sample analysis. Minimum power is 16 watts during the long pump-down period. Average power is 18 watts.

#### Hygrometer

This instrument is unchanged. It would operate down to about 40 km.

## LARGE PROBE - OTHER CANDIDATE INSTRUMENTS

### X-Ray Fluorescence

The two X-ray fluorescence instruments under consideration are similar. The first has a closed window while the second has an open window. These instruments would operate all the way down, since they can pick up aerosols at upper altitudes as well as dust at lower altitudes. The first represents a more conservative approach.

(It is worth noting that on the handout charts, this is listed as a nominal payload experiment.)

### Gas Chromatograph

This is a good backup for the mass spectrometer. If the problems of building this have been solved for Viking, then it may be a good candidate. It has a bad reputation -- it works well in the laboratory, but there are problems in getting a flyable model. The instrument cycle time is 20 minutes. It is proposed to take three samples, and hence requires at least a 60-minute descent. It requires venting of 4000 cc's of He into the pressure vessel.

### Attenuated Total Reflection Spectrometer

This instrument is derived from a common industrial lab apparatus, but none has ever been flown. It is not much burden to the spacecraft; it heats its own window.

### Wind Drift/Altitude Radar

There are three candidates here. The first is the Singer Kearfott radar. There were no real surprises in their final report. The weight was down to 8.5 pounds, but we are conservatively taking 10 pounds. There is a good chance of reducing the power. The antenna design has a hole in the center that might be used for a shock wave radiometer light pipe. The radar will measure winds up to 30 m/sec with a few cm/sec accuracy. At probe angles from 5 to 10 degrees, the data degrades, but the allowable wobble is now stated to be 10 degrees. Wind drift is obtained to altitudes of 40 km; the altimeter only operates up to 20 km. They have gone back to an air vented waveguide (from a ceramic guide). The planar array can be curved in one direction but not both, and they would prefer not to bend at all. The final report is stamped "for official use only" because of proprietary data, and so can't be made available to Hughes (although excerpts might be).

The second radar is a coherent S-band radar (Brown's radar). It is very heavy, probably prohibitively heavy and also has a large size. The data rate is large because the wind drift data processing is not done on board. The antennas are not defined in the proposal.

The third candidate is a simple altimeter which would operate from 50 km to the surface. It has a 50 to 100 meter accuracy. You don't have an altitude reference with the temperature pressure structure experiment unless you reach the ground (except for the pressure reference). If you flew one of these things, this would be its prime purpose. The weight does not include the antenna weight (for a 1 db antenna). The instrument is not at all critical. It has been flown on balloons extensively. If the wind drift radar isn't flown, then this is an interesting candidate.

#### Atmospheric Electrical Phenomena Detectors

This is really three experiments in one: RF noise, atmospheric conductivity, and electric field detector. It is proposed at a very unrealistic 3/4 pound. This doesn't really show the extent of the interface problem. There are a lot of wires running in and out of the pressure vessel. There is a problem of how to separate spacecraft induced phenomena from atmospheric phenomena. A high impedance feedthrough in the pressure vessel is required.

#### Electrostatic Probe

This was a very spotty proposal, and the data given here is more than we know, but supposedly the proposer knows what he is doing.

SMALL PROBE - NOMINAL PAYLOAD

Temperature Gauge

Unchanged.

Pressure Gauge

Unchanged.

Accelerometer

Unchanged. /

Nephelometer

Three have been proposed. Two are the same instruments proposed for the large probe. The third would use an external light source and a reflector mounted on the probe antenna. This doesn't have any chance of being accepted because it looks back into the wake.

Magnetometer

Unchanged. This instrument needs a spin index pulse.

## SMALL PROBE - OTHER CANDIDATE INSTRUMENTS

### Radar Altimeter

Same instrument proposed for the large probe.

### Net Flux Radiometer

This is a nice instrument but has demanding interface requirements, e. g., a deployable boom with a rotatable mirror. It would be desirable to have a solar radiometer on day-side probes.

## PROBE BUS - NOMINAL PAYLOAD

(NOTE: Charts are in inverse order of importance)

UV Spectrometers

Two UV spectrometers have been proposed. The first is a straightforward derivation from the Mariner instrument. It has a wide range of data rates. It wants to operate from 5000 km down, and wants to traverse the limb. The second is a lighter weight instrument.

Exospheric and Ionospheric Probe

This is a set of three instruments, which has been sketchily proposed, but looks interesting. We don't have much data on it, but will look further at it. It has been built, at least brass-boarded in portions.

UV Fluorescence

The night-side entry requirement for this instrument makes it unlikely that it will be flown.

Magnetometer

Unchanged.

Electron Temperature Probe

This instrument is strictly a Langmuir probe. Larry Brace at Goddard has been flying this instrument for 10 years.

Retarding Potential Analyzer

This instrument would measure both electron temperature and ion temperature and is in competition with the preceding instrument. There is a possible misprint in the chart where it says that the spacecraft is to have a minimum conductive area of 2325 in<sup>2</sup>.

Ion Mass Spectrometer

Two instruments have been proposed plus a combined neutral-ion mass spectrometer. The Bennett instrument looks like it would put the smallest burden on the spacecraft.

Neutral Mass Spectrometer

Here there is a choice between a magnetic deflection instrument and a quadrupole instrument. The main difference is the resolution you get out of them. Both are demonstrated instruments. Weight of the second is probably closer to 7 pounds. The first experimenter says that data after 135 km is useless, but this is a conservative view.



17.0 INTERDEPARTMENTAL CORRESPONDENCE

TO: Distribution D

DATE: 13 March 1973  
REF. HS507-0455

SUBJECT: Ames Visit on 9 March 1973

FROM: A. M. Lauletta/  
R. A. Park

BLDG. 376 MAIL STA. 11141  
EXT. 84509/82320

A. M. Lauletta and R. A. Park of Hughes met with S. C. Sommer and D. Kirk at Ames to discuss instrument requirements for the accelerometer, pressure and temperature sensors in the large and small probes for Pioneer Venus.

A general discussion of constructing the Venus atmosphere from the data provided by these sensors was held. Key points were:

- Errors in the knowledge of probe mass, drag coefficient and area all directly affect the determination of atmospheric density. An error of 1% appears to be acceptable.
- Initial conditions of probe velocity and flight path angle are required for the atmospheric structure experiments.
- Instrument accuracy for vertical profile measurements are: temperature and pressure 1%, acceleration .1%.
- For atmospheric dynamics (i.e., relative measurements between probes) pressure and temperature accuracies of .1% may be required. Dr. R. M. Goody was referred to in this context.
- The relatively high mass loss of phenolic nylon and resultant unknown in drag coefficient and area, perhaps 2% to 3%, affects atmospheric density reconstruction. An error of less than 1% is required. It appears that this could be met with a low ablator such as carbon phenolic. Further discussions should be held in this area because of its impact on overall probe design.
- Repackaging of the accelerometer system appears quite feasible, it has inherent circular features. Significant progress in reducing the sensor's volume may result in its use in both the small probe and large probe.
- Upper operating temperatures of these sensors were pursued with Ames personnel with the following results:

Temperature (electronics)	150° to 160°F
Pressure (electronics)	150° to 160°F
Accelerometer (sterilization)	255°F
Accelerometer (electronics)	150° to 160°F


A-299



General

At a later meeting S. C. Sommer and Dr. John Wolf, Branch Chief, Space Physics, ARC, discussed program implications concerning Thor Delta vs Atlas Centaur in relationship to the chances that Wolfe would have to get his solar wind probe experiment on the probe bus mission. (Wolfe is confident that he will be on the orbiter mission, and his type of experiment has number one priority in the SSG orbiter report of January 1973.) The discussion was vehement, but the general view seemed to be that the probe missions might be delayed to 1978, and if so the Atlas Centaur would be the launch vehicle. (There was not explanation for this choice, although the issue was raised.) If the Atlas Centaur is used, the implication was that there would be no payload limitation and thus the probe bus payload could be very large and include Wolfe's approximately 7 pounds experiment. Wolfe's experiment consists of a large bank of channeltrons which measure the mass and energy distribution of particles in the solar wind. He will have no difficulty mounting it on the orbiter configuration which would use an experiment like his Pioneer 6 through 9 designs with spin axis perpendicular to the ecliptic or use the design for Pioneer F&G, with its spin axis in the ecliptic for the probe bus.

  
A. M. Lauletta

  
R. A. Park

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## 18.0 INTERDEPARTMENTAL CORRESPONDENCE



TO: Distribution "D"      CC:

ORG:

DATE: 15 March 1973  
REF. HS507/0461

SUBJECT: Meeting with  
Dr. M. Kolpin  
and Dr. L. Harnett

FROM: R. A. Park/A. M. Lauletta  
ORG. 44-24

BLDG. 376      MAIL STA. 11141  
EXT. 82320/84509

On Monday, 12 March 1973, A. Lauletta and R. Park had a meeting with Drs. Kolpin and Harnett of TRW on the subjects of the Hoffman (University of Texas, Dallas) mass spectrometer and the Thunder Inc. hygrometer experiments. Both Kolpin and Harnett are physicists in the Fluid Dynamics Department at TRW. By way of background, Kolpin apparently in connection with TRW's work on Pioneer Venus, examined the GSFC mass spectrometer with its substantial requirements for explosive valves for atmospheric sampling at various altitudes. TRW had already developed a ceramic micro-leak (CML) inlet system on other program, and Kolpin proposed the use of this device to Dr. John Hoffman at the University of Texas at Dallas, since it eliminates the requirement for a large number of separate explosively actuated inlets. Hoffman agreed and Kolpin is now responsible for the entire inlet system.

The experiment uses a double focussing magnetic sector mass spectrometer developed by Hoffman for the Apollo program. It uses only five explosive switches and weighs 18 pounds. It has two separate inlet systems, one for taking a single sample in the upper atmosphere to isolate the rare gases. This system has a single opening and a single closing valve system with the opening coinciding with the cap removal for both inlet systems. The rare gas measurement unit thus operates only once on a single sample. It is vented into the common ionizing chamber of the CML system and from there it is analyzed like the gas from the continuous leak inlet. The second inlet is open constantly after the cap is removed. The CML minimizes the leak rate keeping the total accepted by the mass spectrometer within an order of magnitude over the entire entry, thus making it possible for the ion pumps to handle all the gas that enters during descent.

Both inlets require heating and are 1/10-inch tubes of any suitable material. They are housed in a larger tubular structure which supports the penetration. They should be mounted not more than 60-degrees from the stagnation point. The cap is mounted to the tubes or the outer wall of insulation if there is one. The mass spectrometer is designed to work up to 60°C. The inlet system will work up to 600°C (I think).

The hygrometer was developed by Dr. Harnett for an earlier program. It uses a Brady array developed by a coinvestigator, Bennitz of Thunder Inc. It is very light and costs very little and, hence, should have a good chance of being selected. However, at present, it does not have a team member

Meeting with  
Dr. M. Kolpin  
and Dr. L. Harnett

Ref: HS507/0461  
Page: 2

representing a University or NASA center. The major problem is to keep liquid HCL or  $\text{SO}_4$  away from the sensor which is sensitive to these liquids. They believe they have achieved a suitable gaseous liquid separation technique using a standing corner vortex. They gave us a copy of the hygrometer proposal which is available. They did not give us a copy of the mass spectrometer proposal but suggested we ask Dr. Hoffman.

The configuration of the hygrometer is similar to that shown in our February baseline. Configuration discussions on the probe mass spectrometer were not too fruitful. As expected, the large dimensions are primarily dictated by the analysis chamber (double focusing or quadrapole) which in turn is directly related to particle deflection requirements to obtain the basic data. It was further stated that electronic separation from the ionization and analysis chambers would be ill-advised since high voltages are involved. We intend to pursue this further at the Tucson meeting including Dr. Hoffman.

Both TRW personnel appeared very cordial and quite willing to cooperate in assisting us now or in the future.

  
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R. A. Park

  
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A. M. Lauletta

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## 19.0 INTERDEPARTMENTAL CORRESPONDENCE



TO: Distribution D  
ORG:

CC:

DATE: 22 March 1973  
REF. HS507-0467

SUBJECT: Recent Soviet Papers Dealing  
with Venus Missions

FROM: R. E. Daniel  
ORG. 40-92-20

BLOG. 376 MAIL STA. 8115  
EXT. 84893

A visit was made to the UCLA Engineering and Mathematics Library to evaluate the latest (and hence, untranslated) papers published in Soviet Journals that deal with Venus missions. Several interesting papers were found in the leading Soviet space research bi-monthly journal, "Cosmic Research" (Kosmicheskie Issledovaniya).

The March/April 1972 issue had a paper by V. V. Kerzhanovich describing wind velocity and turbulence measurements based on doppler data from Venera-4, Venera-5 and Venera-6. The computational and measurement techniques to derive this data were described in greater detail than in previous Soviet papers.

The short term stability of their oscillator was  $0.8-1.5 \times 10^{-9}$ , which corresponded to a wind velocity error of 0.25-0.5 m/sec from this error source. The oscillator was calibrated throughout the cruise phase by comparing vehicle velocity measurement with one-way doppler (open loop) and with two-way doppler (closed loop).

Venera-4 landed approximately 16 degrees north of the sub-earth point. This allowed horizontal and vertical wind velocity measurements. However, Venera-5 and Venera-6 landed very close to the sub-earth point and thus, allowed only vertical wind velocity measurements. Also frequency drift of the Venera-5 and Venera-6 oscillators were greater than expected and the accuracy of the measurement was degraded to 4-7 m/sec. Since the vertical wind component was very low, the absolute measurements were of little value. Average vertical wind pulsations were measured at approximately 0.3 m/sec.

Figure 1A shows the flight doppler data from Venera-4. It also shows the predicted frequency drift of the reference oscillator as a function of temperature during descent. This data was used to correct the flight data. Figure 1B shows a corresponding plot of wind velocity as a function of height. A maximum velocity of approximately 50 m/sec was measured at a height of 51 km. Wind direction was from the north pole to the equator. Velocity decreased to near zero at 40 km. These computations have an overall systematic error of +10.5, -9.5 m/sec.

The May/June 1972 issue of "Cosmic Research" had a paper by V. V. Kerzhanovich, M. K. Rozhdestvenski, et al, describing wind velocity and turbulence measurements from Venera-7 doppler data. Venera-7 landed 11°20' east of the sub-earth point. This allowed computations of the horizontal and vertical components of the wind velocity.

Once again, the stable oscillator frequency was calibrated during the cruise phase. Frequency drift during the last month was  $2.15 \times 10^{-8}$ . The maximum error was  $\pm 6$  Hz, which corresponded to a systematic error from this source of  $\pm 2$  m/sec.

Wind velocity for Venera-7 was computed by comparing the doppler velocity data with three different velocity calculations that utilized flight measured temperatures, atmospheric models, and known mass, volume, aerodynamic drag, and effective cross section area of the capsule/chute system. The difference between each of the calculated curves and the doppler data is the desired wind velocity and is plotted in Figure 2. Positive wind direction is from the antisolar point to the morning terminator. The maximum systematic error was  $\pm (7.5-9.5)$  m/sec. Although the curves show a wind direction change at 45 km, this may represent only a magnitude change. The large systematic error may move the curves over by the magnitude of the error.

The wind velocity near the surface (0 to 3.5 km) was computed assuming wind velocity at the surface itself was zero (see Figure 3). Wind direction is from the morning terminator to the antisolar point. If this assumption is not valid, this curve shows the velocity difference between the surface and the plotted points.

Analysis of the Venera-7 flight and test data indicated that the surface bearing strength was between  $2 \text{ kg/cm}^2$  and  $80 \text{ kg/cm}^2$ . This eliminated the possibility that the capsule landed on a liquid surface.

The July/August 1971 issue of "Cosmic Research" had a paper entitled, "Preliminary Results of the Venusian Atmosphere Investigations from Venera-7," authored by M. Ya. Marov, V. S. Avduyevski, et al, which provided preliminary flight data and also some details of the chute system not found elsewhere. Venera-7 used a single stage chute system with an extraction (pilot) chute. It had a variable canopy area to allow relatively rapid descent at higher altitudes. The chute was deployed initially in a reefed configuration (at approximately 55 km) when the descent velocity was approximately 120 m/sec. The chute was de-reefed 10 minutes later, increasing the area of the mid-section of the canopy. This occurred at an altitude of approximately 30 km, after the velocity had decreased to 27 m/sec, and resulted in an immediate decrease in velocity to 19 m/sec. During the next 6 minutes the velocity slowly decreased to 15 m/sec. Then an anomalous condition occurred (probably with the chute) and the velocity suddenly increased to 25 m/sec. The total descent time was 35 minutes. The normal time should have been 60 minutes.

The July/August 1972 issue contains a paper entitled, "Cosmic-Ray Measurements on Venera-7," by S. V. Vernov, P. V. Vakulov, et al. Venera-7 used an instrument that measured low energy cosmic rays. Protons in the energy range of 1-5, 4-12 and  $>30$  Mev and electrons in the greater than 0.05 Mev and greater than 0.2 Mev energy range were measured from 17 August to 15 December 1970. Significant increases in cosmic ray levels were recorded in August, November and December.

Subject: Recent Soviet Papers Dealing with Venus Missions

There were also several other papers of an analytical character dealing with Venus studies as described below.

The May/June 1972 issue had a paper entitled, "Some Optical Characteristics of Venus and the Probability of Interpretation of Photometric and Polarization Measurements," by E. M. Feigelson. For future flyby missions the author recommends a UV and IR photographic scanner. For probes he recommends a flux density radiometer that measures upward and downward radiation in the visible and infrared regions, a nephelometer with a polarized light source and a measurement of the solar spectral transmission characteristics in the upper atmosphere (the latter is similar to our Aureole Extinction Detector).

The July/August 1972 issue also had a paper entitled, "Determination of Characteristics of Light Scattering Particles in the Venusian Atmosphere by Photometric Measurements," by Ia. L. Birukov and L. G. Titarchuk.

The September/October 1972 issue had a paper entitled, "The Possibility of Determining Venusian Atmosphere Thermal Profiles by Thermal Radio Emissions," by Ia. M. Timofeev, M. A. Gruzdeva, et al. This paper discusses thermal mapping of the Venusian atmosphere by means of a radiometer from an orbiting vehicle.



R. E. Daniel

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Attachments:

Figures 1 thru 3

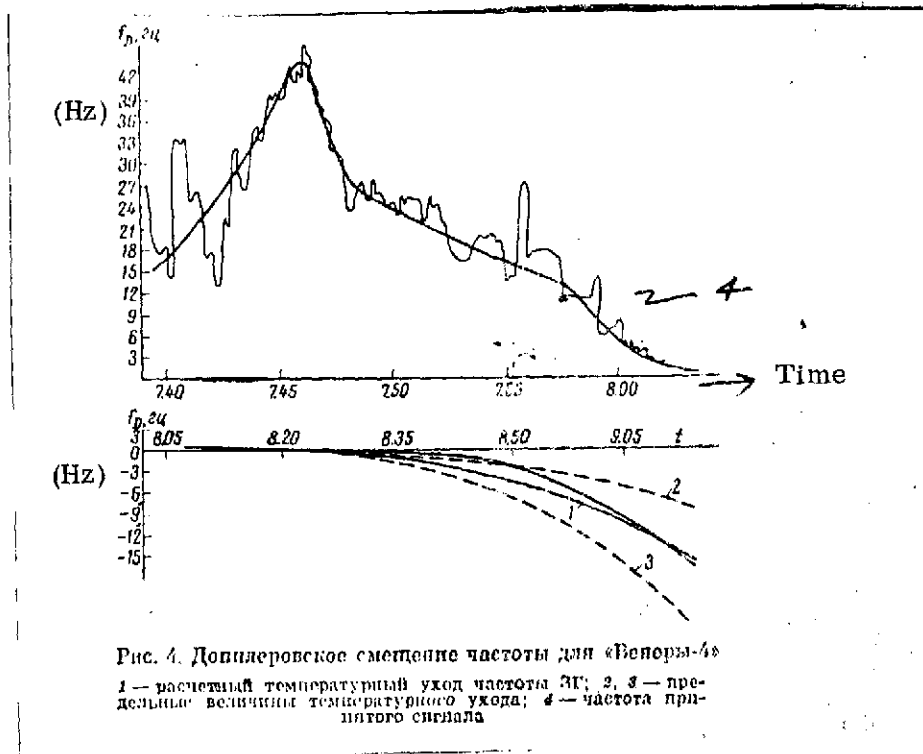


Figure 1A. Venera-4 Doppler Frequency Shift.

Curve 1: Predicted reference oscillator drift from heat sources  
 Curves 2 & 3: Maximum frequency drift from heat sources  
 Curve 4: Frequency of received signal.

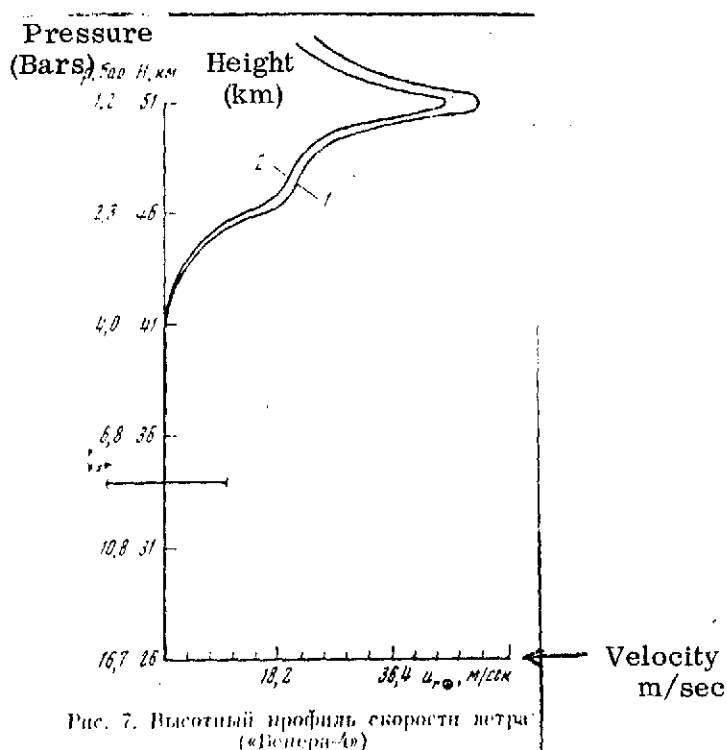


Figure 1B. Venera-4 Wind Velocity Profile as Function of Altitude.

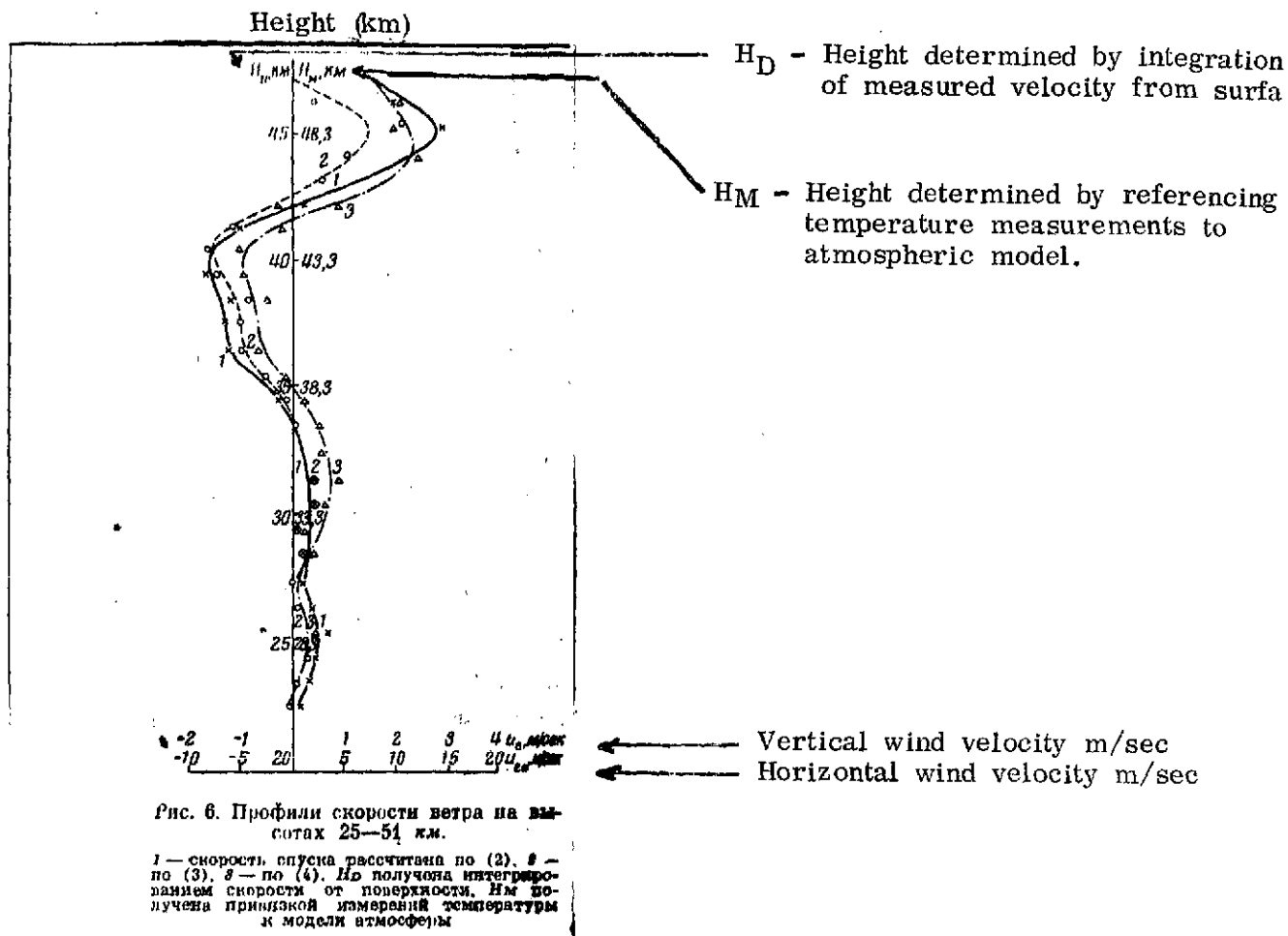


Figure 2. Venera-7 Wind Velocity Profile at 25-51 km Altitudes.

Curve 1: Descent Velocity Computed From:

$$v_{so}^{(1)}(t) = \left[ \frac{2g(M - \kappa \rho(t))}{C_x S \rho(t)} \right]^{1/2}, \quad \leftarrow \text{Quasi-stationary parachute descent formula}$$

Curve 2: Descent Velocity Computed from:

$$v_{so}^{(2)}(t) = T^{1/2}(t) \left[ \frac{T^{1/2}(t_0)}{v_s(t_0)} + \frac{1}{2} \int_{t_0}^t \frac{g d\tau}{R' T^{1/2}(\tau)} \right],$$

Curve 3: Descent Velocity Computed from:

$$t(H) = \int_{H_0}^H \frac{dh}{v(h)}, \quad v_{so}^{(3)}(H) = \left[ \frac{2g(M - \kappa \rho(H))}{C_x S \rho(H)} \right]^{1/2} \quad \leftarrow \text{Pressure derived from measured temperature referenced to } H_D = 31.7 \text{ km in atmosphere model}$$

where

$g$ = Venus Gravitational Acceleration	$R'$ = $\frac{R_0}{\mu}$
$\rho$ = Density of atmosphere	$R_0$ = Gas constant
$M$ = Capsule mass	$\mu$ = Molecular weight
$\kappa$ = Capsule volume	$H$ = Height, $H_0 = 31.7$ km
$C_x$ = Drag coefficient of chute & capsule	$T$ = Temperature
$S$ = Effective cross section area of chute & capsule	$t$ = Time



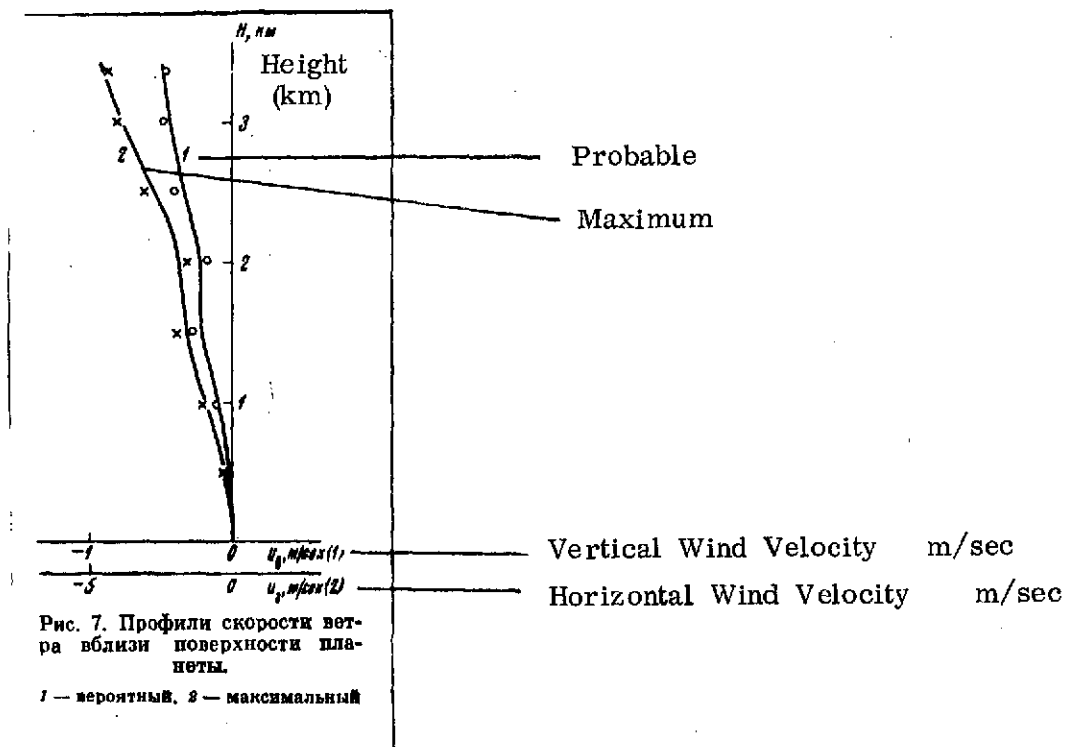


Figure 3. Wind Velocity Profile Near Planet Surface  
(Venera 7)



JET PROPULSION LABORATORY California Institute of Technology • 4800 Oak Grove Drive, Pasadena, California 91103

2 April 1973

## 20.0 Expected Beam Track During Occultation

Mr. A. Parks  
Hughes Aircraft Company  
MS 11141  
P. O. Box 92919  
Los Angeles, California 90009

Dear Andy:

I am enclosing copies of plots of the expected beam track during Pioneer Venus occultations that have been prepared by Dr. Gunnar Fjeldbo. The plots show the direction to the image of the earth as seen from the orbiting spacecraft for orbits at insertion and 35 days after. The orbital data were taken from Lou Acheson's (Hughes) note to me.

The cone angle is measured from the spacecraft earth vector. Zero clock angle is defined in the usual manner with reference to Canopus.

Throughout the mission the clock angle varies between 0 and  $360^\circ$  and the cone angle between 0 and  $75^\circ$ . Note, however, that the signal intensity falls off very rapidly with increasing cone angle, so that it may not be necessary for the spacecraft high gain antenna to track the larger cone angles.

If you have any questions please call me (x6164) or Dr. Fjeldbo (x2422). In the interest of fairness this information is also being provided to Mr. J. Love of TRW.

Sincerely,

A handwritten signature in cursive script, appearing to read 'Arvydas J. Kliore'.

Arvydas J. Kliore  
Member of Technical Staff  
Tracking and Orbit Determination  
Section

AJK:lm

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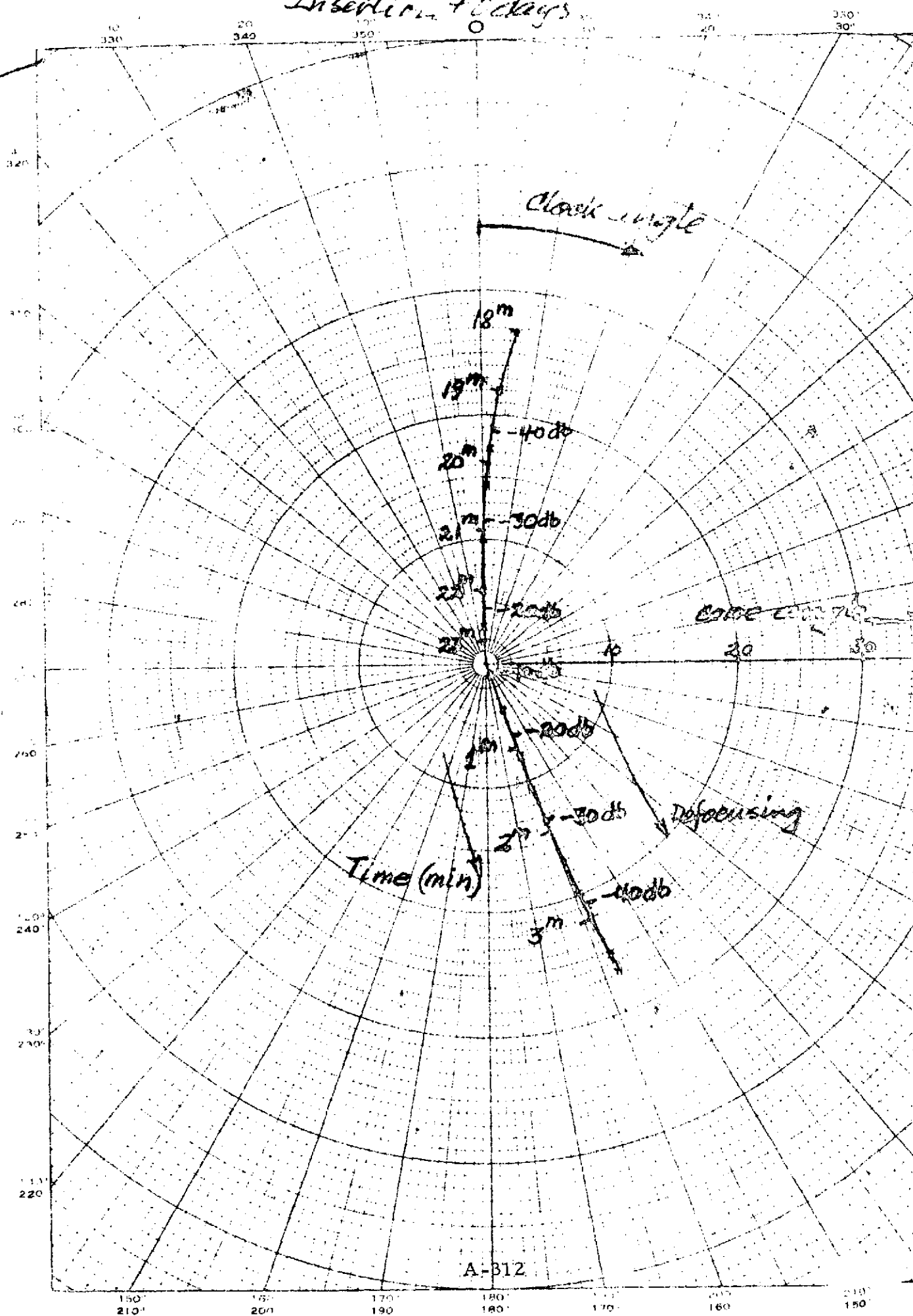
Enclosure

A-311

# Insertion + 8 days

EUGENE DIETZEN CO.  
MADE IN U.S.A.

EUGENE DIETZEN CO. 15 1/2  
POLAR CO-ORDINATE



A-312

Insertion + 35 days

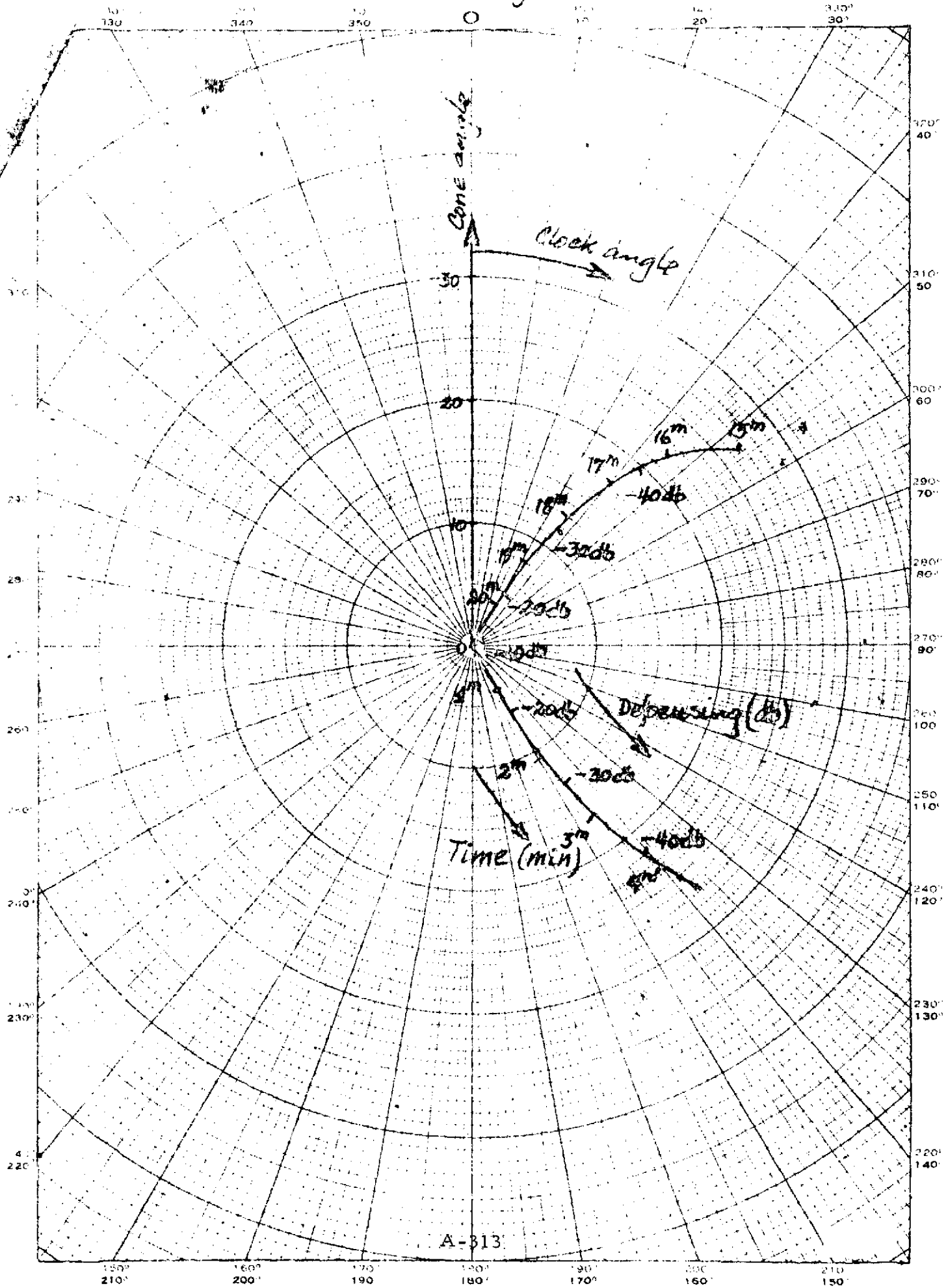


Fig 2

## 21.0 INTERDEPARTMENTAL CORRESPONDENCE



TO: Distribution D.  
ORG:  
SUBJECT: Science Trip Report

CC:

DATE: April 4, 1973  
REF. HS507-0480

FROM: A.M. Lauletta, Jr.  
ORG. 44-23-00

BLDG. 376 MAILSTA. 11141  
EXT. 8-4509

On the 19th of March the writer and R.A. Park planned to visit with Dr. R. Knollenberg to further discuss the Cloud Particle size analyzer and some recent Hughes spin tunnel tests, Dr. J.C. Gille of NCAR and Dr. A.I. Stewart (Univ. of Colorado) on the UV Spectrometer. All were conveniently located in the vicinity of Boulder, Colorado.

After braving severe air turbulence and a north pole like blizzard we were able to meet with Drs. Knollenberg and Stewart; Gile had to leave for Washington D.C. earlier than planned.

Following are notes on the highlights of this meeting.

Dr. Knollenberg Visit

Dr. Knollenberg now has a small company "Particle Measuring System" within shouting distance of Ball Bros.

We verified the power as 15-20 watts. He was not enthusiastic about power cycling (1/100) as the Science Steering Group (SSG) notes appeared to indicate, although it is possible.

We discussed installation and the spin tunnel smoke tests on the pressure vessel. He felt it appeared satisfactory but he required more detailed data on flow with particles rather than an aerosol from four microns to one-half a mil.

He stated his alignment requirements would be about one milli radian.

The external condensing mirror does not require heating. He proposes using a "thermal well" technique used on earth atmosphere programs successfully. The mirror blank is about 1/8 inch diameter by 1/8 inch thick.

The heating technique for the pressure seal window he preferred was a thin film heater. When questioned about the upper temperature operating limit (we suspect a maximum of 500°F) he thought they would survive to 1000°F (were designed to 1200°F). We pursued the type of heater and where we might get additional information on it without being too fruitful. We intend to investigate this further since we would probably prefer such a heater since it offers greater efficiency than our wire wrap type, if it can survive to the surface. He also mentioned that the heater could be localized on the surface of the window where the two beams penetrate rather than the entire surface.

A-315

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He thought his unit could operate, perhaps somewhat degraded, to 125°C.

He preferred mounting directly to the pressure vessel wall, rather than a shelf, to ease the alignment/integration problem. In further discussions on installation and alignment it became clear that detail discussions with pressure vessel designers is required as one gets deeper into mechanical details. From our limited discussions we certainly feel that Dr. Knollenberg can contribute in a significant way in this area. We suggested he visit us in Los Angeles for technical sessions with key designers. He agreed but no date was set at this time; we both thought it would be advisable to await experiment selection and then work through NASA/ARC.

The lens assembly could be shifted with respect to the longitudinal axis of the box.

The box could be made rectangular.

The optical line of site could be shifted or deflected by prisms.

For the two small windows alternate design, they are essentially in the same tube 1/4 inch apart.

The He-Ne laser operates at 6328 Å.

Location at the equator of the pressure vessel, perpendicular to the spin axis is preferred. Indentation of the pressure seal window from the exterior surface is required to minimize particle contamination. Large particles would have difficulty flowing into the well rather than by it. A further improvement is achieved by designing a simple labyrinth along the walls of the indentation, trapping particles. This would hopefully allow the elimination of more exotic cleaning techniques.

A cutaway view of the experiment is attached.

#### Dr. A.I. Stewart

Although not in our nominal science payload for the Probe Bus, UV Spectrometer were listed in the "other instrument" category and have a good chance of being selected. Dr. Stewart is in LASP at the University of Colorado; they have extensive UV experiment experience in space (Dr. C. Barth).

UV observations would be required on the probe bus to about 130 KM from the surface.

He would like to observe the entire planet in the instrument FOV prior to scanning measurements. This would require the bus to be oriented, spin axis looking at Venus perhaps some 4 x 10<sup>6</sup> KM (≈ 4 days) before encounter. The instrument FOV is about 1.5 degrees.

In the scanning mode 60 rpm is desired; it provides simpler instrument operation.

Scanning through the dark side limb is required. For the spin axis aligned along velocity vector (mass spectrometers and earth look angle) the instrument would require a small offset from pointing directly along the spin axis, a function of the number of limb crossings and locations vs. altitude before burn up.

Dr. Stewart would like to see some data on bus targeting, velocity vector orientation, altitude, etc. to be able to derive scanning programs. Based on our discussions he feels there should not be any problems in accommodating his experiment for look angle or scanning requirements.

After concluding our Boulder visit we then journeyed on to Tucson for the annual DPS (Division for Planetary Sciences of the American Astronomical Society) meeting.



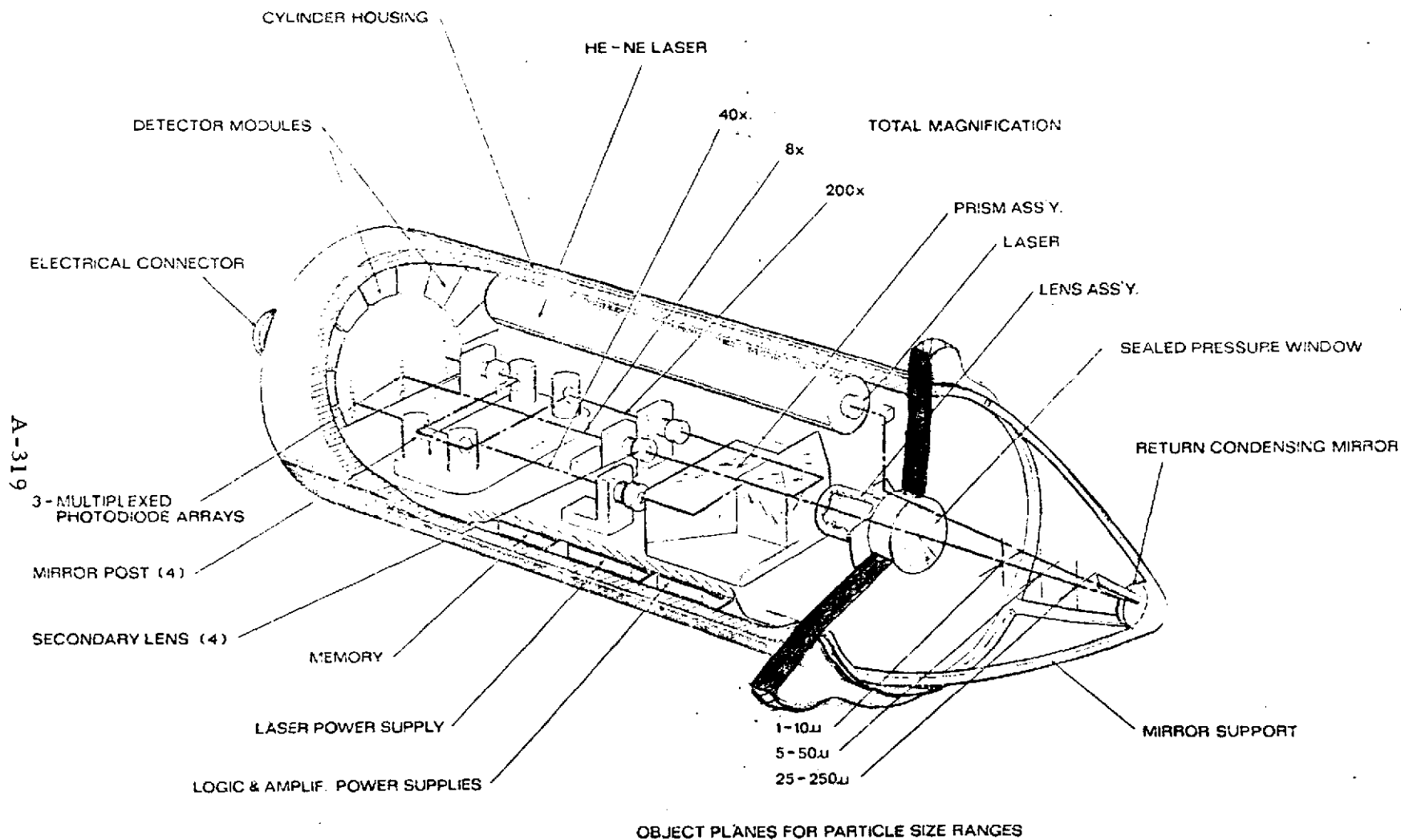
A. M. Lauletta, Jr.

AML:vv

Attachment - 1 p

# PROPOSED PIONEER VENUS CLOUD PARTICLE SIZE SPECTROMETER

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TO: Distribution D  
ORG:

CC:

DATE: 13 April 1973  
REF. HS507-0532

SUBJECT: AAS Division of  
Planetary Sciences  
Meeting in Tucson

FROM: L. K. Acheson  
ORG. 40-91-00

BLDG. 376 MAIL STA. 11141  
EXT. 81086

The third annual meeting of the Division of Planetary Sciences of the American Astronomical Society was held in Tucson, 20-23 March 1973. This is the most active division of the AAS and it brings together scientists from many different disciplines to exchange information on the latest findings in a rapidly moving field.

Attached is a copy of the printed abstracts, and write-ups of several of the more important review papers, plus one added paper. Notes on all talks are available in my files.

L. K. Acheson

LKA:mj

Attachment 1 - 5 pp  
2 - 2 pp  
3 - 4 pp  
4 - 1 p  
5 - 26 pp

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VENUS - PARTLY UNVEILED

T. M. Donahue



This talk should be considered as footnotes and asides on recent developments, since there have been several good recent reviews in the literature.

Interior

There has been a development of Urey's old theory of condensation by Lewis which predicts the absence of water and a low abundance of sulfur on Venus.

Surface

Venera 8 landed on 22 July 1972 and sent back 50 minutes of data.



A gamma ray spectrometer determined the abundance of potassium, uranium, and thorium to be 4 percent,  $2 \times 10^{-4}$ , and  $6.5 \times 10^{-4}$  respectively, which is indicative of granitic rock and appears to demonstrate Wassenberg's universal abundance rule.

From radar measurements the surface appears to be a fluffy substance with  $1.5 \text{ g/cm}^3$ .

Published results of Venera 7 give a temperature of  $737 \pm 20^\circ \text{K}$  and a pressure of  $90 \pm 15 \text{ kg cm}^{-2}$ . The inferred temperature and pressure at the radar surface are  $750^\circ$  and  $92.2 \text{ kg cm}^{-2}$ .

A series of low frequency measurements from earth have accumulated, which indicate the following black body temperatures:

A-323

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430 MHz	$523^{\circ} \pm 28^{\circ}$
408 MHz	$546^{\circ} \pm 29^{\circ}$
608 MHz	$548^{\circ} \pm 33^{\circ}$

The Venera 7 data would predict a temperature 50 degrees higher, i.e.,  $594^{\circ} \pm 12^{\circ}$ . This is a perplexing result for which we have no explanation. You should get the same temperature at decimeter and decameter wavelengths.

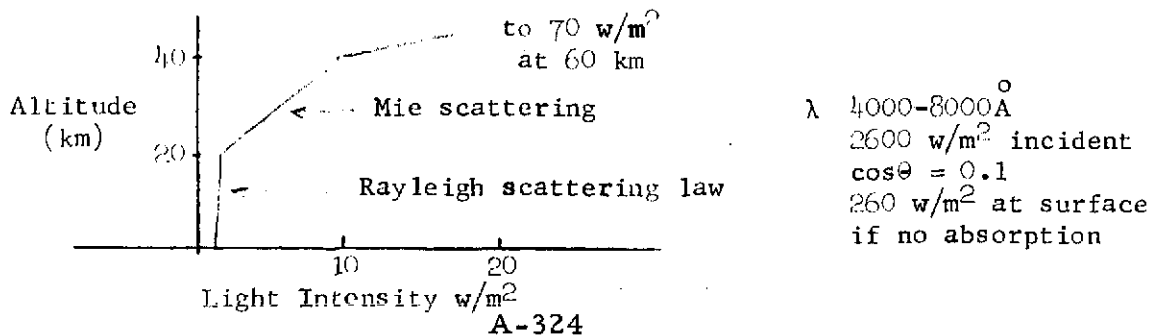
#### Atmospheric Composition Below Clouds

The major accomplishment of the Venera probes is in assessing the  $\text{CO}_2$  abundance at between 90 and 95 percent and in detecting a little nitrogen on the planet, but there were disquieting observations of water vapor, at a height of 55 km, decreasing toward the surface.

$\text{CO}_2$	$97^{+3}_{-4}\%$
$\text{N}_2$	$<2\%$
$\text{H}_2\text{O}$	1.1% at 55 km 0.21% at 46 km $10^{-4}$ at 30 km

Venera 8 also purported to measure an abundance of ammonia of  $10^{-2}$  to  $10^{-1}$  percent at altitudes of 46 to 33 km. We would like to take a good look at the method of measurement.

Another very exciting result from Venera 8 involves the penetration of light to the surface.



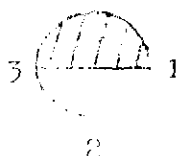
At 40 km the intensity is  $10 \text{ w/m}^2$ , at 20 km it is slightly greater than 1, and at the surface  $0.6 \text{ w/m}^2$ .

Above 20 km altitude the optical depth is 5, which is good for the greenhouse effect.

### Clouds

The less I say here the better. The highest layer of clouds is at 80 km (5 mbar) and  $175^\circ$ . This has been considered to be other than water-ice clouds. Hartke suggested they might be some kind of acid such as HCL. I understand we will hear about sulfuric acid from the Youngs. I would remind you of Lewis' prediction that iron sulfide should not condense out of the atmosphere. One might invoke a comet.

As you go further up in the atmosphere, you are at cloud layers where a 1/2-day rotation is observed in UV. Two types of motions are observed: one accelerates as the day progresses:



- 1) 50 m/sec at sunrise
- 2) 100 m/sec at noon
- 3) 130 m/sec in the afternoon

The second is a more diffuse motion of about 140 m/sec all day.

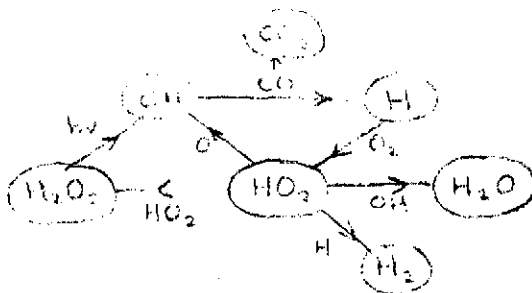
### Composition of the High Altitude Atmosphere

The atmospheric composition at high altitudes from spectroscopic measurements is:

$\text{H}_2\text{O}$	$10^{-4} - 10^{-6}$
$\text{CO}$	$4.6 \times 10^{-5}$
$\text{O}_2$	$5 \times 10^{-6}$
$\text{HCl}$	$6 \times 10^{-7}$

The low abundance of CO and  $O_2$  (not only on Venus but on Mars) raises the question of why the  $CO_2$  atmosphere is so stable, since it decomposes so easily and recombines so difficultly.

During the past year, with regard to Mars there has been a convergence of explanations.



McElroy and Donahue

Parkinson and Hunten

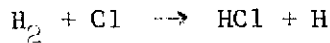
This chemistry is under the tight control of escape from the atmosphere of Mars.

Venus also should show itself as an atmosphere in which  $CO_2$  is stable in spite of the fact that the escape flux of hydrogen is very low, as evidenced by the Mariner 5 spectrometer, and in spite of the fact that in a massive planet like Venus, escape of oxygen can't occur.

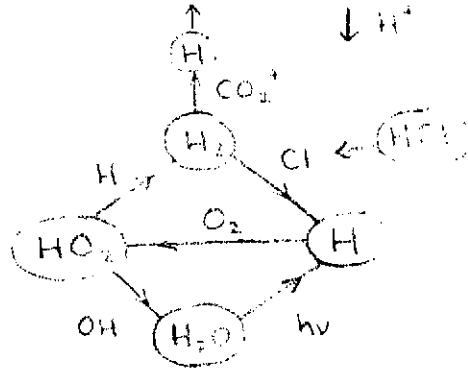
New developments are that Hunten has estimated the convection of hydrogen in the form of  $H_2O$  and  $HCl$  in Venus. With the upward flux you arrive at far too low amounts of H for the escape fluxes measured. Therefore, there must be molecular hydrogen in the atmosphere to provide this. The  $H_2$  and  $CO_2^+$  reaction would give atomic H to escape.

This is also a part of a mechanism McElroy and his students have developed for Venus. One first assumes no water in the atmosphere of Venus. The escape flux of hydrogen is in balance with the influx of hydrogen from the solar wind. Therefore, one doesn't need to balance  $O_2$  with hydrogen escape.

# Photolysis of HCl



The same basic recombinations hold for Venus as for Mars, but the additional hydrogen chemistry for Venus is:



This scheme works in spite of low  $\text{O}_2$  abundance at the cloud top level, because of massive amounts of H from the HCl reaction.

This promising result is the fruit of aeronomy and chemistry to account for atmospheric stability. This is where we stand.

## Discussion

Rasool - An agreement has been concluded with the Soviets for an exchange of results on Mars and Venus. By April 15 we will get Venera 8 data (including photometer data and surface chemistry). As published, the data will be out in several months, but write me for earlier results.

Hunten - A comment regarding the escape of hydrogen from Venus. Hydrogen should be escaping at a much greater rate than inferred from the Mariner 5 measurements, rather than a much smaller rate.

# INTERPLANETARY RESULTS FROM PIONEER 10

M. S. Hanner, Dudley Observatory

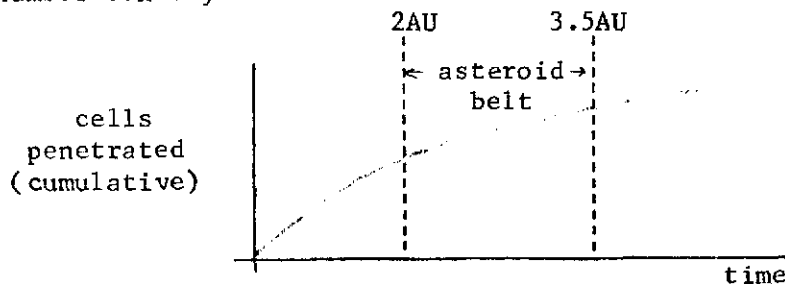
Pioneer 10 was launched on 3 March 1973, and is still alive and well. It is 3.89 AU from the sun. The round trip light travel time from earth is 74 minutes. Jupiter encounter will occur on 4 December 1973.

Pioneer 10 has a 9-foot diameter antenna and an 8-watt transmitter. Power is supplied by RTGs (30 watts). A magnetometer is mounted on a 20-foot boom, to measure magnetic fields to a fraction of a gamma. The spacecraft is spin stabilized with a period of 12.5 seconds. There are 11 scientific instruments on board: a solar wind probe, 2 instruments for cosmic rays, a UV photometer (which has measured a He to H ratio of 1/10 in interplanetary space, an IR radio-meter, 2 meteoroid detectors (one utilizing pressure cells and one optical), an imaging photopolarimeter (primarily for Jupiter but also for the zodiacal light).

The imaging photopolarimeter operates in two bands: 4000-5000Å, and 6000-7000Å. Sky maps are being made during the cruise phase. The first region looked at, by necessity, was the region opposite the sun -- the gegenschein region. At 9 million km from earth, the gegenschein was still seen with the same slope and brightness as seen from earth, therefore it is not an earth-based phenomenon. The fall-off of absolute brightness with distance goes as  $1/r^2$ . If the particle density were constant it would fall off as  $1/r$ , thus the dust is falling off at about  $1/r$ . This indicates that the particles causing gegenschein are not all out in the asteroid belt.

Suddenly, within a week's time, all brightness sources decreased just about in the position of Mar's orbit. (This was not an instrument calibration change.) After this time the gegenschein superposed on the Milky Way and couldn't be observed. As the spacecraft came out of the asteroid belt, very low intensities were observed. The dust particles are of a  $\mu$  or submicron in size.

Another experiment measured  $10\mu$  size particles. This showed a constant flux out from earth through the asteroid belt, i.e., a constant number density.



There is a density of  $10^{-9}$  part/m<sup>3</sup> of  $10^{-9}$  gm or larger.

Soberman has an experiment to measure larger particles, of 1/10 to 1 mm diameter. In the asteroid belt the net hits increased by a factor of 2 or 3. Orbits have been computed for 2 particles: a  $250\mu$  particle with a semi-major axis of 1 AU and an eccentricity of 0.25, and a  $25\mu$  particle with a semi-major axis of 7 AU and an eccentricity of 0.9. Outside of the asteroid belt he is not finding anything, the count is very low.

One final result is the solar wind measurement. Pioneer 9 and 10 happened to be lined up when on 2 Aug. there was a spectacular solar flare, with the highest solar wind ever recorded: 1000 km/sec at Pioneer 9 (at 0.7 AU) and 700 km/sec at Pioneer 10. The energy decreased by a factor of 2, between Pioneer 9 and 10. Where did it go?



SATELLITES AND ASTEROIDS: A REVIEW OF RECENT WORK

D. Morrison, Institute for Astronomy, U. of Hawaii

There are 32 known satellites and 1800 named asteroids. There is increased interest in these smaller bodies, as evidenced by the number of contributed papers. Last year there were 15 papers, a half-day session, and this year a whole day.

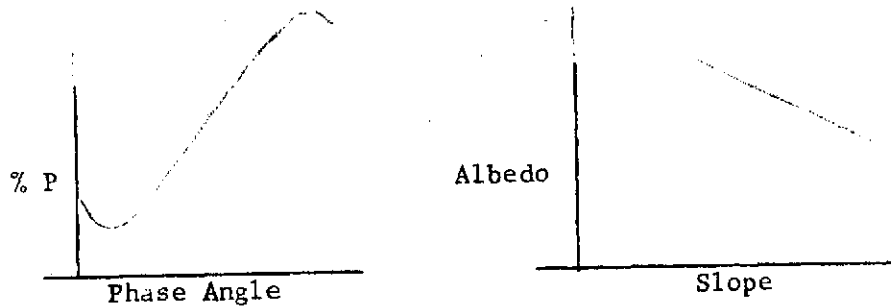
I will be giving my subjective feeling of what is most important. We will be talking about the surface and physical properties of these objects, not the orbits.

In the last year we have the ability to measure size and albedos. If the albedo is known we can measure size. Three new techniques have been applied in the last three years.

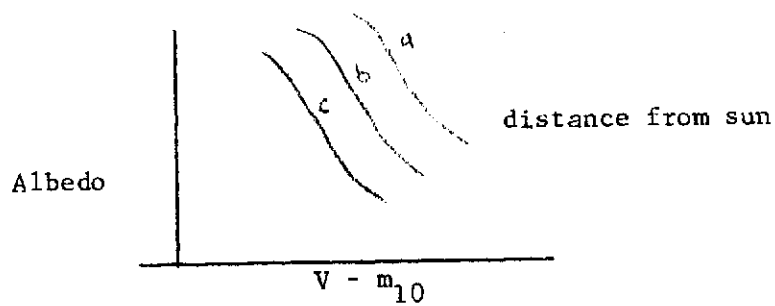
Visually, Callypso and Ganymede have a diameter greater than 1 arc sec. With a resolution to tenths of an arc sec, the precision is no better than 10 percent. Visual techniques over the last 80 years have been reviewed by Dollfass. The sizes of the four Galilean satellites, Titan, and the three largest asteroids were determined.

The first new size determining technique involves the timing of an occultation of a star by a small object. This gives size to 5/1000 of an arc sec. Io and Ganymede have been very accurately determined.

The other two methods involve determining the albedo. The first obtains the albedo from the linear slope of the curve of polarization vs. phase angle. The slope is closely correlated to albedo, and not with properties of the surface such as particle size.



The second technique utilizes IR radiometry combined with visual. The photometer measures reflected sunlight and the IR measures absorbed and reemitted radiation.



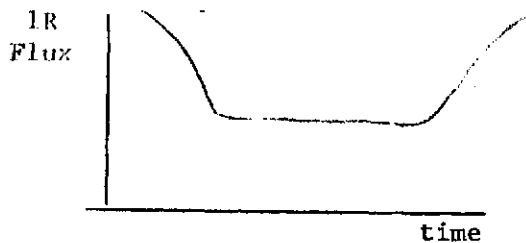
Both of the above techniques give geometric albedos. Comparing the radii obtained with different methods:

	<u>Visual</u>	<u>Occultation</u>	<u>IR</u>
$I_o$	$1750 \pm 75$	$1820 \pm 10$	$1930 \pm 200$ km

	<u>Visual</u>	<u>Polarization</u>	<u>IR</u>
Ceres	385	610	530 580 430 525

For Ceres it is seen that the older value is too low.

At the meeting in Kona last year there was considerable discussion of the thermal physics of the Galilean satellites, as determined from the eclipse cooling curve.



The only way a two layer model makes sense is a frost/ice system. Sometimes Io doesn't seem to warm up after an eclipse.

Regarding the surface composition of the Galilean satellites, there has been very good work with spectrometers in the 1 to  $4\mu$  region which indicates water-frost, a result not inconsistent with the thermal physics.

Regarding satellite atmospheres, there has been evidence for years from the post eclipse brightness of Io which might indicate an atmosphere. The most important satellite with an atmosphere is Titan. Kuiper found methane in 1944. Trafton found the S' quadrupole line of hydrogen.

1.6 km atm	16 mb	methane
.5 km atm	6 mb	hydrogen

Pollack estimates a minimum surface atmosphere of 0.1 atm.

One question is whether we are seeing light scattered from clouds or the surface. Titan's color reflectivity is virtually identical with Saturn, therefore it similarly is from clouds. It is believed we are dealing with an optically thin atmosphere above a cloud layer.

IR can explore the lower atmosphere, and the presence of a large greenhouse effect is indicated. At  $10\mu$  the brightness temperature

is  $125 \pm 2^\circ$ , at 17 to 28  $\mu$ ,  $93 \pm 2^\circ$ . Above the clouds a spectrometer indicates hydrogen and methane. There is a much more massive atmosphere below the clouds. Hunten suggests nitrogen. The most detailed model is due to Pollack.

The Titan atmosphere doesn't seem to be stable. It seems to be in a blow off condition.

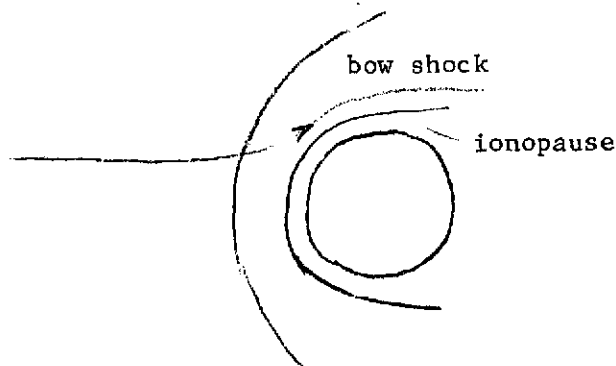
There is continuing work on asteroids. The spectrophotometer is a very powerful tool. If we could find where meteoroids come from it would be useful.

Soon we will have to treat these satellites and asteroids as places, and not just point sources that get in the way of other observations.

## SOLAR WIND SWEEPING OF THE UPPER ATMOSPHERE

F. Curtis Michel, Rice University

There are two possible mechanisms for loss of a planetary atmosphere: evaporation, and solar wind sweeping. The latter is directly applicable to Mars.



From Mariner measurements, the mass loss is:

Mars      2.2 g/sec

Venus     29.4 g/sec

C\_\_\_\_\_ and Daniel independently compute solar wind sweeping rates of:

Mars      8 g/sec

Venus     12 g/sec

For heavy ions the cyclotron ratio can be very large compared to scale height. The correction for this is  $\times 10$  for Mars and  $\times 2\frac{1}{2}$  for Venus, which yields:

Mars       $8 \times 10 = 80$  g/sec

Venus      $12 \times 2\frac{1}{2} = 30$  g/sec

The Mars number would correspond to 0.7 mbars/aeon, therefore the solar wind didn't blow away an earth-type atmosphere.

# CONTRIBUTED PAPERS: Venus

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## Are the Clouds of Venus Sulfuric Acid?

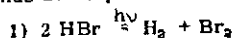
A. T. YOUNG and L. G. YOUNG, Jet Propulsion Laboratory, Pasadena, CA 91103. - Water solutions of sulfuric acid, containing about 75%  $H_2SO_4$  by weight, have a refractive index within .01 of the values deduced from polarimetric observations of the Venus clouds. These solutions remain liquid at the cloud temperature, thus explaining the spherical shape of the cloud particles (droplets). The equilibrium vapor pressure of water above such solutions is .01 that of liquid water or ice, which accounts for the observed dryness of the cloud region. Furthermore,  $H_2SO_4$  solutions of such concentration have spectra very similar to Venus in the 8-13 micron region; in particular, they explain the 11.2 micron band. Cold sulfuric acid solutions also seem consistent with Venus spectra in the 3-4 micron region. The amount of acid required to make the visible clouds is quite small, and is consistent with both the cosmic abundance of sulfur and the degree of outgassing of the planet indicated by known atmospheric constituents. Sulfuric acid occurs naturally in volcanic gases, along with known constituents of the Venus atmosphere such as  $CO_2$ ,  $HCN$ , and  $HF$ ; it is produced at high temperature by reactions between these gases and common sulfate rocks. The great stability and low vapor pressure of  $H_2SO_4$  and its water solutions explain the lack of other sulfur compounds in the atmosphere of Venus--a lack that is otherwise puzzling. Sulfuric-acid precipitation may explain some peculiarities in Venus and Mariner data. Because sulfuric acid solutions are in good agreement with the Venus data, and because no other material that has been proposed is even consistent with the polarimetric and spectroscopic data,  $H_2SO_4$  must be considered the most probable constituent of the Venus clouds.

## Sulfuric Acid in the Clouds of Venus.

Godfrey T. Sill, The University of Arizona - Polarization studies of the clouds of Venus yield information as to the particle size and shape (1.1  $\mu$ spheres) and refractive index ( $1.46 \pm 0.02$ ). The clouds are strong desiccating agents and typically show UV and IR absorptions. Sulfuric acid of approximately 86% concentration fulfills many of the properties of the clouds.

86% sulfuric acid freezes near 273°K; the frozen droplets would have  $n = 1.45$  at 235°K and 3500Å. The ambient  $H_2O$  vapor pressure of 86%  $H_2SO_4$  solution is  $10^{-4.3}$  mb at 235°K -- the value found for the upper Venus atmosphere. The infrared transmission of films of sulfuric acid closely match the IR albedo of Venus from 1.7 to 4.0  $\mu$ .

The chemical mechanism for producing sulfuric acid involves the oxidation of  $SO_2$  to  $H_2SO_4$  by means of elemental bromine in the upper Venus atmosphere. The reactions are:



The reaction involves using  $Br_2$  as a carrier catalyst in the oxidation of  $SO_2$  and involves loss of  $H_2$  from  $H_2O$ . The  $HBr$  is photolytically dissociated by solar UV longer than 2300 Å.

$HBr$  gas of mixing ratio  $10^{-5.3}$  is compatible with the Venus-UV spectrum from 2000 to 2300 Å, and  $Br_2$  dissolved in sulfuric acid produces visible and near UV absorption compatible with the albedo of Venus.

## Aircraft Observations of the Near Infrared Spectrum of Venus: Implications for Cloud Composition.

JAMES B. POLLACK, Edwin Erickson, Charles Chackerian Jr., Fred Witteborn, Audrey Summers, and Betty Baldwin, NASA Ames Research Center-- Observations of Venus between 1.2 and 4.5 microns were obtained from a NASA operated Lear Jet using a filter wedge spectrometer. Similar observations of the sun permitted a direct determination of Venus' reflectivity spectrum. Venus' reflectivity is characterized by an absence of strong spectral features in the 1.2 to 2.5 $\mu$ , other than those attributable to carbon dioxide absorption, and a very low reflectivity between 2.9 and 4 microns attributable in part to absorp-

tion by the cloud aerosols. Absorption by carbon dioxide is chiefly responsible for a decline in the reflectivity longward of 3.6 microns. The observed spectrum is compared with a large number of theoretical reflectivity spectra that encompass all the proposed candidates of cloud composition.

## A Search for $H_2O$ and $O_2$ on Venus.

W. A. TRAUB and N. P. CARLETON, Smithsonian Astrophysical Observatory and Harvard University. - We have searched for the  $H_2O$  (8197.71Å) line on Venus at high resolution (instrumental width = Venus line width = 25 mÅ) with the PEPSIOS spectrometer. A preliminary analysis shows no spectral line stronger than about 0.1 mÅ at the expected position when the Venusian phase angle was about 160°; however, at a phase angle of about 30° we do see an absorption line within 10 mÅ of the expected position with a strength of about 0.5 mÅ. These results are internally consistent if one allows for the facts that at high phase angles all Venusian lines weaken due to the cloudy atmosphere, and also that the water vapor is not expected to be well mixed.

We have also searched for  $O_2$  (7635Å) on Venus, finding an upper limit to the equivalent width of about 0.13 mÅ, which is about a factor of 20 lower than any previously published results. An interpretation of these measurements will be given in terms of a scattering model of the upper atmosphere.

## Observations of the Venus Water Vapor Line at 8197Å over the Disk of Venus. E. S. BARKER, Univ. of Texas McDonald Obs.

- As part of the continuing observational program at McDonald Obs., the several lines in the 8200Å water vapor band are monitored as frequently as possible to detect any variation in the observed abundance of Venus water vapor "above the clouds". Both 2 Å/mm spectrographic plates and photoelectric scanner observations have been taken since mid-1970. Recently on several occasions good seeing and a large disk diameter have allowed spatial resolution over the disk of Venus. Variations in the water vapor abundance have been found with both position and time. The data consist of photoelectric spectrum scans made with the 107-inch échelle-coude scanner at a resolution of about 60mÅ (FWHM). No systematic variation with either position and/or time has been noted. In the period between August and mid-December 1972 the observed abundances for various positions on the disk ranged from 45 to 55 microns of ppt. water vapor. These abundances have been calculated from equivalent width measurements of the 8197.71Å water vapor line assuming a temperature of 250°K and pressure of 100 mb. The range of values (5 to 55 microns) for the total line of sight abundance falls between the 3.8 microns reported by Fink, et al. (Icarus 17,617,1972) for the total disk and the <64 to 160 microns reported by Schorn, et al. (Icarus 10,98,1969). For several days during September, abundance comparisons were made with the  $CO_2$  band strengths at the same location on the disk of Venus and with the presence of UV clouds.



# Variations in Spectroscopic Abundances of H<sub>2</sub>O and HCl on Venus. R.G. Prinn, Dept. of Meteorology, MIT

The spectroscopic abundances observed for HCl and H<sub>2</sub>O in the upper atmosphere of Venus are dependent upon the interaction of a number of critical factors: (1) the vertical temperature profile and the saturation vapor pressure of these gases over cloud particles of HCl (sg), H<sub>2</sub>O (S), and HCl. 3H<sub>2</sub>O (S), (2) if temperatures are low enough for condensation of such cloud particles, the particle number density and vertical and horizontal extent of the resultant high-altitude haze, (3) the single-scattering albedos and phase functions of these cloud particles at the wavelengths of the various observable HCl and H<sub>2</sub>O bands, (4) the vertical transport of these gases by eddies and mean motions, and their relative humidity and lifetimes for photochemical decomposition in the upper atmosphere. Considerable variations in the observed abundances of these gases in different wavelength regions and at different times and places are theoretically plausible, and may have been observed.

Spectra of Venus With "Connes Interferometer" Analyzed for Best Temperature and Pressure Fits. R.S. Pierrehenriot, Concordia College, and Uwe Pinn and R. P. Larson, Lunar and Planetary Laboratory. - In the spring and summer of 1971, we obtained a number of spectra of Venus with the "Connes Interferometer" set up at the Steward Observatory 90 inch telescope. The spectra extend from one to three microns, and cover phase angles from 20 to 77°. Some of the molecular bands appearing in these spectra are analyzed for best temperature and pressure fits. We present data on four hot bands, and on three regular bands of CO<sub>2</sub>, and on the 2-0 band of CO. They all give roughly the same temperature (250±10°K) and a pressure of about 75 mb. The agreement of the hot band temperatures with the other temperatures suggests strongly that the visible cloud deck on Venus must have a relatively sharp boundary for the radiation.

A Comparison of Venus Cloud Models Determined by Spectroscopic Investigations. J.L. Regas, Calif. State Univ., Chico, L. P. Giver, R.W. Boese and J.H. Miller, NASA, Ames Res. Ctr. - The properties of our single cloud layer models of the Venus clouds determined from observations of the 1.05μ CO<sub>2</sub> band are compared with the two layer models of Chamberlain and Smith (1972, Ap.J. 173, 401), Carleton and Traub (1972, BAAS 4, 362) and Hunt (1972, JQSRT 12, 405). All our single cloud models have anisotropic scattering mean free paths typical of terrestrial stratus or cirrus clouds, 0.1 to 0.25 km. The lower dense cloud in Hunt's two layer model has a mean free path of 0.01 km, a value typical of terrestrial cumulus clouds. This very short mean free path places severe constraints on either the nature of the condensate composing the lower cloud or on particle transport in the upper troposphere. The existence of the lapse rate change from 9°K/km to 4°K/km at the 58 km level reported by the Mariner V investigators has been used in support of two layer models with a clear region between the layers. However, the clear region in the two layer models falls above the 58 km level in the Venus atmosphere, whereas for our condensation cloud model with the highest bottom the lapse rate change occurs close to the cloud bottom. If the 4°K/km lapse rate is

the moist adiabatic lapse rate, then it should occur within the cloud rather than in the region between cloud layers. Hunt has found that the equivalent width of weak CO<sub>2</sub> lines formed in his two layer model increases with phase angle near superior conjunction. Because the observations of Young et al. (1971, Acta Astronomica 21, 329) show a similar increase and because none of the single cloud layer models which Hunt considered showed this increase, he concluded that the data of Young et al. proved the existence of two separate cloud layers. Because the phase variation of weak CO<sub>2</sub> lines computed by Regan (1967, Ph.D. Thesis, Harvard Univ.) and Hansen (1969, Ap. J., 158, 357) using a single cloud also show this increase, we conclude that neither the data of Young et al. nor the Mariner V lapse rate change requires two cloud layers with a clear region between.

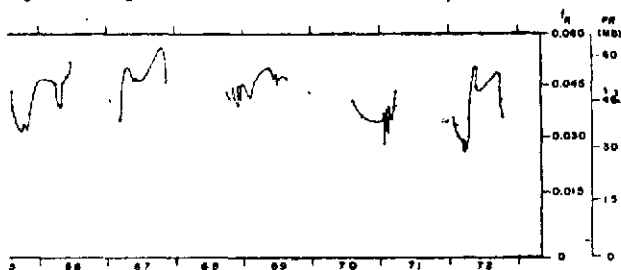
Weather on Venus? RONALD A. SCHORN, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California 91103 and EMMET S. FARMER, University of Texas, Austin, Texas 78712 - During the September-October Venus patrol, we used the large image scales of the 82 and 107 inch telescopes to study the variations in CO<sub>2</sub> band (7820, 7883, 8589, 10,362, 10,488, and 10,677 Å) intensity in localized regions on Venus.

Venus CO<sub>2</sub> Observations at Inferior Conjunction: Variations with Time and Position on the Disk. E. S. FARMER, Univ. of Texas McDonald Obs. and R. A. SCHORN, JPL. - Venus was observed at McDonald Obs. with the 107-inch and 82-inch coude spectrographs during Venus's 1972 inferior conjunction. The CO<sub>2</sub> band at 10489Å was observed over phase angle ranges of 154 to 176° and 175 to 148°. After inferior conjunction between phase angle 167 and 150°, the CO<sub>2</sub> bands at 7820Å and 8589Å were observed with the 107-inch coude scanner. Observations of all three bands were made within one hour on seven days at the same locations on the thin crescent (about one arcsec in diameter). The observed portions of the crescent were centered at latitude points 0° and +45° with respect to the intensity equator. CO<sub>2</sub> abundances have been derived and show variations up to a factor of 3 for different locations on the crescent on a single day. The abundances for a specific location on the crescent also varied with phase angle. The different bands show the same general abundance variation with position for individual days. The rotational temperatures were derived only for the 10489Å band because of the intrinsic weakness of the other bands at these large phase angles.

Further Observations of Weather on Venus. L. G. YOUNG, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California 91103 - During the past elongation of Venus we had a joint spectroscopic and photographic three week patrol of that planet. The observatories involved were Lowell, Mauna Kea, McDonald, Paris, Table Mountain and New Mexico State University Observatory. Some of the spectroscopic results obtained at Table Mountain will be presented and discussed. These results will be published in the 1 April 1973 issue of the Ap. J.

#### Venus: Ultraviolet Polarization Variations.

D.L. COFFEEN and A.L. BAKER, Lunar and Planetary Lab., University of Arizona - The linear polarization of sunlight reflected by Venus shows much detail when observed as a function of wavelength and phase angle. Most of the features arise from scattering by spherical particles in the upper cloud levels; a comparison of the observed features with realistic cloud models leads to a unique deduction of limits on the particle size and refractive index, as shown by Hansen and Hovenier (J. Atmos. Sci., in press, 1973). Rayleigh scattering is also found in the polarization, strongest in the ultraviolet near 90° phase angle. Hansen deduces a mean pressure of 50-20 mb at the level where the scattering optical depth is unity. However, the Rayleigh scattering contribution to the observed polarization is not constant with time. We have continued the ultraviolet patrol of Venus global polarization at 0.365  $\mu$ m, begun by Gehrels in 1959. The figure shows the past 7 years of data. All explicit dependence on phase angle has been removed, to show the variation of the equivalent gas pressure at the cloud tops ( $\tau = 1$ ). Thus the global average changes by more than a factor two. We are planning a more intensive 30-day patrol, in a joint program with spectroscopic observers.



#### Evaluation of the Circulation Patterns of the

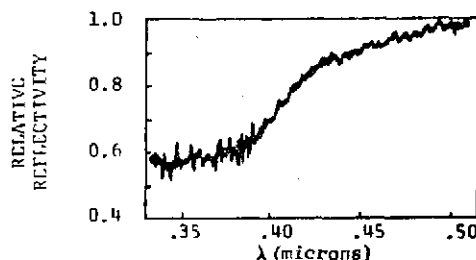
Upper Cloud Deck of Venus. R. Beebe, H. Reitsema, E. Reese and A. Scott, NMSU - Markings recorded on photographs of Venus taken in ultraviolet light appear to be randomly distributed in longitude and quite ephemeral in nature, rarely lasting for more than 20 days and usually much less. Analysis of these markings indicates a general planet-wide circulation in the upper atmosphere with velocities from -80 to -130 m/sec at the equator.

Derivation of the rotational velocities by the analysis of recurrence of 67 similar patterns yields a distribution with a primary peak corresponding to a sidereal rotation of 4.0 days and a secondary peak at 4.6 days retrograde. This behavior suggests that observational bias from single station observations may influence the data strongly. Further investigation shows that distributions of features with lifetimes from 4 to 20 days and rotation rates represented by Gaussian distributions with mean periods between 4.25 and 4.30 days yield bimodal distributions similar to the observed data when the observational bias is taken into consideration.

#### Relative Spectrophotometry of Ultra-

violet Clouds on Venus. J. H. WOODMAN and E. S. BARKER, Univ. of Texas McDonald Obs. - Low resolution (~10Å) photoelectric spectral scans from 3300-5100Å were obtained for various regions on the disk of Venus on several days with the coude scanner of

the 107-inch telescope. Ratio spectra between regions appearing bright and dark in ultraviolet photographs produce the relative spectral reflectivity of the ultraviolet clouds. On 10 September 1972 area scans at eight wavelengths between 3300-5100Å were obtained in addition to spectral scans, and both produced consistent results. Observations on different days reveal the same general spectral characteristics although the relative spectral reflectivity between areas on the planet's disk is variable. It is shown that effects due to the variation of atmospheric refraction with wavelength must be considered in spatial studies involving spectra covering long wavelength ranges. Our observations have been corrected for these effects. Comparison is made with the area scan observations of Coffeen (p.84, Planetary Atmospheres, IAU Symp. 40, 1971). The ratio spectrum of a particularly dark ultraviolet cloud to a relatively bright region on 10 September 1972 is shown below.



## CONTRIBUTED PAPERS: Mercury, Venus and General

A New Upper Limit for an Atmosphere of CO<sub>2</sub> on Mercury. R. F. POPPEN, UWE FINK, and H. P. LARSON, Lunar & Planetary Laboratory, University of Arizona - Spectra of Mercury obtained 1971 Nov. 1, 2, 3, with the "Connes interferometer" at the Steward Observatory 90" telescope are analyzed for a possible CO<sub>2</sub> atmosphere. The bands best suited for this purpose are the triad of bands 201 I, 201 II and 201 III around 5000 cm<sup>-1</sup>. The resolution limit of 0.135 cm<sup>-1</sup> is good enough to separate any Mercury CO<sub>2</sub> lines by means of the Doppler shift of 0.26 cm<sup>-1</sup>. A preliminary analysis indicates that there cannot be more than 0.5 cm-atm (STP) of CO<sub>2</sub> on Mercury. This new upper limit is about a factor of 1000 smaller than previous determinations.



Mercury and Venus: High-Resolution Radar Topographic Profiles. G.H. PETTINGILL, MIT, Dept. of Earth and Planet. Sci., D.B. CAMPBELL and R.B. DYCE, Cornell Univ., NAIC Arecibo Obs., and R.P. INGALLS, MIT, Haystack Obs. — Surface height profiles for limited, near-equatorial regions of Mercury and Venus have been obtained in 1972 using delay-doppler radar techniques (see, for example: Ingalls and Rainville, *Astron. J.*, 77, 185-190, 1972) at the Arecibo and Haystack Observatories. At 70-cm wavelength (Arecibo), the surface resolutions in longitude, latitude, respectively, were 0.29°, 2.0° (12, 85 km) for Mercury, and 0.29°, 1.0° (30, 103 km) for Venus. At 3.8 cm (Haystack), the corresponding resolutions were 0.75°, 3.1° (32, 130 km) for Mercury, and 0.25°, 0.81° (26, 85 km) for Venus near inferior conjunction. Typical relative height measurement accuracies for these data were of the order of 150 m.

The maximum excursions in surface height observed were approximately 3 km for Mercury and 5 km for Venus. Anomalous results obtained near Venus longitudes of 100° and 109° are interpreted as caused by mountains 1 to 2 km in height.

The support of the National Science Foundation and the National Aeronautics and Space Administration is gratefully acknowledged.

Some Properties of Oblique Angle Radar Returns from Venus at 70 cm Wavelength. D.B. CAMPBELL and T. HAGFORS, National Astronomy and Ionosphere Center, Arecibo Observatory, Arecibo, P.R. — A series of observations designed to map the reflectivity of Venus at 70 cm with the Arecibo radar were carried out during the 1972 conjunction. The data obtained for this purpose is here analyzed to determine the mean scattering behavior of Venus both in regard to intensity and polarization. The results are compared with the corresponding properties of lunar radar echoes. It is found that the backscattering per unit surface area for circularly polarized illumination depends on angle of incidence as  $\cos^n \theta$  with  $n \sim 1.8$  for both the polarized and the depolarized components. The power ratio at these two components at grazing incidence appears to approach approximately 6 db. For the moon at this frequency  $n$  lies between 1.0 and 1.5 for the polarized and equals 1.0 for the depolarized component. Their ratio approaches 4 db. A much more spectacular difference in the scattering behavior of Venus and the moon lies in their ability to convert circularly polarized illumination into linearly polarized echoes. The degree of linear polarization of lunar echoes increases monotonically toward the limb approaching 17% at 3.8 cm and 35% at 23 cm wavelengths. For Venus at 70 cm wavelength no linear polarization can be detected at grazing angles of incidence, but there is a barely significant indication of a positive effect at intermediate incidence angles. The interpretation of these results in terms of surface models is highly speculative, but several suggestions are offered.

Results from the Radar Imaging of Venus done during the 1972 Inferior Conjunction at 70 cm Wavelength. D.B. CAMPBELL, National Astronomy and Ionosphere Center, Arecibo Observatory, Arecibo, Puerto Rico — Improvements made to the 70 cm wavelength radar system of the Arecibo Observatory early in 1972 gave an increase in sensitivity of almost a factor of ten. Radar

interferometric observations of Venus were made during the conjunction of that year with resolution on the surface ranging from 80 km by 80 km to 200 km by 200 km. The usual radar maps of the ratio of the reflected power to that expected from a homogeneous surface with the same average backscattering properties have been prepared.

Radio Interferometric Observations of Venus near 1.35 cm Wavelength - Implications for the Middle Atmosphere. M. A. JARDEEN, Jet Propulsion Laboratory. A two-element radio interferometer was used to observe Venus at  $\lambda$  1.35 cm in January 1971 and September 1972. The first zero crossing of the observed visibility, i.e., the interferometer fringe spacing which just resolves the disk, was determined from the two sets of data. The observed zero crossing occurs for a fringe spacing distinctly less than that which would resolve a uniformly bright disk. The degree of limb darkening implied is consistent with emission from a model atmosphere based on spacecraft data in which  $\text{CO}_2$  is the dominant source of opacity in the region around the 10 atm pressure level. The observations are not consistent with models in which there is absorption at higher altitudes, which would further enhance the limb darkening. In particular, an optical depth exceeding 0.05 due to absorption above the one atmosphere pressure level is excluded. For example, this sets an upper limit on the liquid water content of the visible clouds of  $0.07 \text{ g/cm}^3$ . Also, at pressures less than a few atmospheres, water in vapor form would absorb strongly in the 1.35 cm line; the upper limit to the water vapor mixing ratio is  $2 \times 10^{-3}$  if the mixing ratio is assumed to be constant beneath the visible clouds.

\*The author acknowledges support by an NRC Resident Research Associateship.

An Exact Expression for the Temperature Structure of a Simple Planetary Atmosphere. B. R. BARKSTROM, High Altitude Observatory, National Center for Atmospheric Research\*. — An exact, analytic expression for the temperature structure in a radiative equilibrium planetary atmosphere is shown, allowing isotropic scattering of the incident solar radiation. The atmosphere is assumed to be homogeneous, plane-parallel, semi-infinite, and having separate gray opacities for solar and for thermal radiation. Simple expressions are shown for the albedo at a given latitude, the Bond albedo, the effective temperature, and the temperature at the bottom of the atmosphere.

The expression for the temperature is evaluated for a solar single scattering albedo of 0.99 using various ratios of solar to thermal opacity. Among the interesting phenomena that appear in the computations are an increase in the altitude of the maximum solar heating as the sun sets, and an angle of incidence for which the Eddington approximation for the solar radiation is nearly exact. The Eddington approximation for the solar radiation is also found to give bottom temperatures accurate to within a few percent of the exact solution. Finally, it is shown that solar radiation does not have to penetrate to the surface of the planet to give a strong greenhouse effect.

\*The National Center for Atmospheric Research is sponsored by the National Science Foundation.

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Loss of Hydrogen from Primitive Atmospheres. D. N. HUNTER, Kitt Peak National Observatory. - It is shown that the rate of loss of hydrogen from a terrestrial planet is controlled by diffusion far more than by Jeans escape. The role of the latter is primarily to determine whether loss is possible at all, and then to set the position and density of the escape level. The diffusive flux is insensitive to temperature and depends primarily on the mixing ratio  $f$  of escaping to background gas. The expression is

$$\phi = \frac{(m_2 - m_1)g}{kT} b \frac{f}{f+1}$$

where  $b$  is the product of the diffusion coefficient and the number density of the background gas. For H and  $H_2$  near  $200^\circ K$ ,  $b$  is approximately  $(1.5 \text{ and } 3) \times 10^{19} \text{ cm}^{-1} \text{ sec}^{-1}$ . For a mixing ratio of unity, a flux in the neighborhood of  $10^{13} \text{ cm}^{-2} \text{ sec}^{-1}$  is found, sufficient to remove, in  $10^9$  years, 3 times as much hydrogen as is now in the oceans. A dense hydrogen corona may be formed, with the escape level at several planetary radii, and for the largest fluxes the escape may be hydrodynamic rather than molecular.

Some New Laboratory Measurements of the Hydrogen Quadrupole Absorption Lines. J. S. MARGOLIS, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California 91103. The absorption strengths of the S(1), Q(1) and S(2) lines of the 1-0 band as well as the S(1) line of the 2-0 band of  $H_2$  have been measured at high resolution. The measurements have been analyzed on the basis of the Galatry Theory of collision narrowing and the results are compared to the theoretical calculations by Birnbaum and Poll, and Dalgarno et al. The new line strengths differ by a small amount from Rank's et al. measurements and are in satisfactory agreement with the theoretical calculations.

A New Laboratory Technique for High Resolution Absorption Spectroscopy over Ultra Long Paths. KENNETH FOX, University of Tennessee, Knoxville,\* and RAYMOND GOLDSTEIN† and VICTOR VALI, University of Washington, Seattle.\*\* - The understanding of vibration-rotation optical spectra of gases in planetary atmospheres has been limited for some time by the lack of suitable laboratory data (Fox, 1972). In order to measure absorption for very weak transitions at low pressures suitable for high resolution studies, very long paths are required. A technique has been developed for obtaining ultra long paths for absorption spectroscopy. The method involves trapping a short laser pulse between two widely spaced retro-reflectors. This pulse is released after traversing the required number of reflections. A total path of 20 km has been achieved in a 1 km long cell, and longer path lengths are feasible with this technique. Applications to measurements of high resolution laboratory spectra of gases of interest will be discussed.

\* Research supported by the National Science Foundation, Grant GA-30713.

† Permanent address: Jet Propulsion Laboratory, Pasadena, California.

\*\* Research supported by the National Science Foundation, Grant GA-30714.

Fox, K. 1972, "High-Resolution Infrared Spectroscopy of Planetary Atmospheres," in Molecular Spectroscopy: Modern Research, ed. K. Narahari Rao and C. Weldon Mathews (New York: Academic Press).

On the Negative Polarization Branch. W. M. SMITH, Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California 91103 and the University of Hawaii, Honolulu, Hawaii 96822. - Most planetary asteroidal, and satellite surfaces exhibit negative polarization at small phase angles (less than  $20^\circ$ ). Ohman (Stockholm Obs. Ann 19 #8 1955) tentatively offered an explanation of this effect as a double reflection from pairs of mutually-perpendicular opaque dielectric surfaces. By using the sphere-sphere model of Bandermann, Kemp and Wolstencroft (MNRAS 199, 291, 1972), which considers double reflection from surfaces that have random orientations, it will be shown that, statistically considered, double reflection produces positive polarization at small phase angles.

A new explanation for the negative polarization is suggested. It considers 3, 4, or more reflections between pairs of spherical particles for which the path length between particles is less than  $\lambda/2$ . The tapering of the space between the particles may be likened to a tapered wave guide which attenuates the waves polarized in the direction parallel to the tapered sides. For the case of reflection between particles, the wave that is polarized perpendicular to their line of centers will have a non-zero electric field component tangent to the surface of the particle. With a partially conducting dielectric, this wave has high attenuation. Hence the predominant emerging polarization is at right angles to Ohman's case.

Path Length Distributions for Photons Diffusely Reflected from a Non-Conservative Planetary Atmosphere. J.F. Appleby and W.M. Irvine, Department of Physics and Astronomy, University of Massachusetts, Amherst, Mass. - The probability distribution of geometric path lengths travelled by photons diffusely reflected from an atmosphere provides the information necessary to compute spectra for arbitrary transmission functions and absorption coefficients of gaseous constituents, and also the time dependent response of an atmosphere to impulsive radiation sources. Graphs to compute this probability distribution are presented for semi-infinite atmospheres for both isotropic and forward directed scattering and for varying amounts of continuum absorption. The distribution can depend sharply upon higher order moments of the single particle phase function, particularly the presence or absence of a backward peak. As a result, the strongly elongated phase functions typical of clouds will in some circumstances more closely mimic isotropic scattering than will the less elongated

phase functions typical of hazes. As the continuum absorption is increased, the distributions approach more and more closely the exponential form predicted for first order scattering, with the result that the distribution broadens sharply for small path lengths. In contrast, in the conservative case the probability distribution falls off extremely slowly for large path lengths, so that considerable care must be taken in performing computations.

## HUGHES AIRCRAFT COMPANY



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## INTERDEPARTMENTAL CORRESPONDENCE

TO: Distribution "D"

CC:

DATE: 11 April 1973

ORG:

REF. HS507-0489

SUBJECT: Science Trip - 5, 6 April 1973

FROM: R. A. Park

ORG. 44-24

BLDG. 376 MAIL STA. 11141

EXT. 82320

On 5 April, Chris Thorpe and Andy Park visited the University of Wisconsin Space Science and Engineering Center and discussed with Dr. V. Soumi, Director of the Center, and T. Haig, Executive Director, the science payload they had proposed for the Pioneer Venus program. The discussion which was very wide ranging and frequently tutorial, lasted more than four hours. Since we were not shown the proposal to NASA, we have only our memories to rely on.

Dr. Soumi apparently proposed to supply the entire small probe pressure vessel since he believes that an integrated science payload is vital to achieving meaningful results. However, it became clear during the course of the discussion that they really did not believe that their approach was necessary or even desirable. The basic payload they proposed consisted of a single radiometer which rotated in such a way that the difference in heat between that emitted from the clouds and from the ground could be determined. Only the net flux (difference) is necessary, not the absolute value. This experiment would determine in part how the heat is contained on Venus. The radiometer sensor needs to rotate in a plane parallel to the spin axis and it could be driven by a motor or as a propeller or in any other way. Ideally, this experiment should be performed near the sub-solar point so that the solar absorption is not masked by the flat look angles of sunrise or sunset; thus the small probe is the better mission. Dr. Soumi also mentioned that Dr. Fymat of JPL has the best experiment but too complex for small probes. (We will see Fymat soon.)

The second experiment will measure how the energy is distributed, using a 0.5 pound and 4-watt altimeter, useful over a 100 km range. It is currently used on their balloon flights and is accurate to 10 cm at 10 km altitude. The altimeter in the three small probes will give an excellent atmospheric pressure and temperature profile for the largely CO<sub>2</sub> atmosphere and the hopefully known W/CnA. Dr. Soumi made the point that temperature and pressure sensors over this large dynamic range and in such a difficult environment are neither accurate nor reliable. The use of altimeter guarantees high accuracy. The University of Wisconsin builds this altimeter using a super regenerative receiver and a phase-locked loop. It has a high gain and is very effective. While only an omni antenna is required, mounting the antenna has not been solved. Mr. Haig talked to GE (where he once worked) and they assured him it could be mounted in the heatshield! In any event, it can, if necessary, be deployed. They showed us a balloon version and it looked to be well made.

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The third instrument proposed is a 1.5 watt transmitter with 3 watts input which has an oscillator stable to  $1 \times 10^{10}$ . It is "locked to a harmonic without loading." This transmitter is also used in their balloon flights and operates in an environment of  $-90^{\circ}\text{C}$  to  $-20^{\circ}\text{C}$ . It uses a "quartz" crystal and is temperature controlled to  $0.01^{\circ}$ .

The fourth experiment is a type of nephelometer using the back scatter from the particles to determine particle flux density. While there was considerable discussion of this instrument, there was little definite detail. Both favored using a tube to pick up particles rather than a window. The instrument sensor would be mounted directly to the end of the tube and would itself be heated to avoid condensation.

On Friday morning, the 6th, we visited the Johns Hopkins group which is headed by Bill Fastie of Ebert-Fastie Spectrometer fame. Mr. Fastie was at Wallops Island but he had set up a meeting with two people - Dr. Paul Feldman of the Physics Department and Dr. John Doering of the Chemistry Department. This group had proposed two experiments; one for the probe bus (and orbiter), and the other for the large probe. The probe bus/orbiter experiment package consists of three related experiments; a far ultraviolet spectrometer, an electron spectrometer and electron probe (Langmuir probe). The experiment for the probe uses the same probe bus/orbiter spectrometer but modified to the near ultraviolet to the near infrared bands.

The probe bus U.V. experiment will measure from  $1140 \text{ \AA}$  to  $1850 \text{ \AA}$  in steps of some  $5\text{-}10 \text{ \AA}$  each. Eighty bps are required from a few thousand kilometers out, and earlier scans of the entire planet are desired. The experiment weighs two pounds and uses less than a watt. The combination electron spectrometer and electron probe weigh less than three pounds and also use less than a watt. The U.V. spectrometer has a small, about 2-inch square cassegranian telescope, which must be mounted to point at a small angle from the spin axis to scan the planet each spin cycle during approach. The spacecraft spin axis must be pointed toward the planet a few days out to provide an overall coverage of the planet before the close approach phase. The field of view of the telescope is  $1^{\circ} \times \frac{1}{2}^{\circ}$ . The electron spectrometer must be mounted to allow uninterrupted flow "through" the instrument and both the electron spectrometer and probe would prefer a positive chassis since both are measuring low energy electronics in the 1 to 2 ev energy regime. The U.V. spectrometer used a grating, mirror, and a photomultiplier for analysis. It will be calibrated in flight, if possible, by observing known stars. The electron spectrometer is basically an electrostatic analyzer, and should not be positioned near assemblies or other experiments that have large magnetic fields; i.e., the mass spectrometer.

The probe spectrometer is the same instrument as the U.V. device, but the telescope is removed and the range changed. The weight and power are about the same. A slipping mirror, periscope and diverging lens would be desirable to measure the energy both upward and downward. However, upward is all that is necessary. A data sample rate, 10 bits (one word) per second is desired and 600 words are scanned in ten minutes. Five hundred and forty (540) samples at 5 Å in the IR and U.V. regions and 60 samples at 50 Å in the visible 10 km resolution is then achieved for one direction viewing. These instruments are all existing and have been flown on Mariner Mars and Atmospheric Explorer.

On Friday afternoon, we visited Goodard Space Flight Center where we discussed the nephelometer they had proposed with Dr. Rudy Hanel and his boss, Nelson Spencer. The actual proposal was made by R. Samuelson who works for Dr. Hanel but he was not available. The following is an abstract from their proposal.

"The intensity and polarization of near infrared backscatter radiation from cloud particles will provide a diversity of answers to fundamental questions about the clouds of Venus. The proposed instrument is a backscatter polarization nephelometer (BPN) which consists of two nested telescopes with coincident optical axes (Figure 5). The inner telescope consists of a 1.4 cm diameter collimating mirror (divergence half-angle =  $2.5^\circ$ ) with a pulsing infrared lamp source ( $0.88 \leq \lambda \leq 0.92 \mu\text{m}$ ) at the focus. The outer Cassegrain telescope (2.5 cm diameter primary) is a radiation collector only; image quality is unimportant. Radiation is pulsed by the source and collimated through a vertically polarizing Glan-Thompson prism; the pulse rate is 12-106 pulses/sec, depending on the probe descent speed. The backscattered radiation is collected by the Cassegrain telescope and analyzed into vertical and horizontal components of polarization by a Wollaston prism, which then directs each state to a separate detector; the two detectors sample simultaneously. The average of 75 samples is taken for each pair of 6-bit data words describing the intensity and state of polarization. Average vertical resolution is 60 meters.

Each detector has a noise-equivalent-power (NEP) of  $2 \times 10^{-14} \text{ w} \cdot \text{Hz}^{-1/2}$ , and saturates (without damage, however) at a signal level of  $2 \times 10^{-4} \text{ w}$ . A maximum signal of  $\sim 10^{-5} \text{ w}$  per detector is expected due to scattered solar radiation. This radiation component, which is probe spin modulated, is removed by enabling the detector channel synchronously with the source and rejecting the low frequency components from further processing. The total instrument is simple, light weight (1.6 lbs.), requires little power (1.3 w) and a low data rate (4 bps), and has no moving parts. The data above have referred to a small probe, although the instrument is equally suited to the main probe."

Some interesting other features of this nephelometer are:

1. It detects particles at a substantial distance from the probe and thus there is little possibility of interference.
2. It uses a Gallium Arsinide infrared lamp, and a PIN silicon photodiode detector.
3. It will provide information concerning not only particle number density but the polarization should give information concerning particle size.
4. Temperature limits are  $-30^{\circ}\text{C}$  to  $500^{\circ}\text{C}$  for optics and  $-30^{\circ}\text{C}$  to  $+55^{\circ}\text{C}$  for the electronics.

RAPark  
R. A. Park

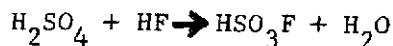
24.0 INTERDEPARTMENTAL CORRESPONDENCE



TO: Distribution C	CC: I. Baker	DATE: 12 April 1973
ORG:	R. P. Reinert	REF. HS507-0497
	P. A. Robinson	
SUBJECT: Trip Report - JPL-Venusian Clouds	D. Stephenson (G.E.)	FROM: P. A. Robinson
	C. C. Thorpe	ORG. 40-92-10
		BLDG. 376 MAIL STA. 11141
		EXT. 8-2733

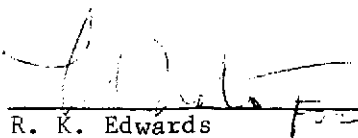
On Monday, April 9, 1973, Leo Nolte, Dick Edwards and Paul Robinson, from Hughes Aircraft Company met with Andy Young from JPL to discuss clouds on Venus. At a recent DPS meeting, Dr. Young had presented his contention that the most probable constituent of the observed clouds on Venus is sulfuric acid. Our purpose in this visit was to understand why he thinks this is so, and what concentrations should be expected. In a forthcoming article in Icarus he explains his model in detail. We now have preprints of that article. The key points of our discussion are listed below.

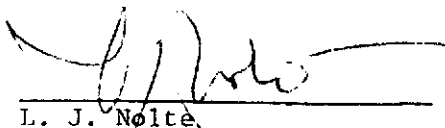
1. The observed clouds are probably  $H_2SO_4$ .
2. One model (Dry Model) predicts a super cooled  $H_2SO_4$  solution. This would imply an "instant" freezing on the surface of the spacecraft as it passes through the clouds.
3. Water vapor, and HF concentration above the clouds may differ above the clouds from below the clouds.
4.  $H_2SO_4$  clouds could be very thick and continuous, ranging from the observed cloud top ( $\sim 68$  km) to the boiling point of  $H_2SO_4$  at 26 km (Wet Model).
5.  $CO_2$ , CO, HCl do not react with  $H_2SO_4$ , however HF does produce fluosulphonic acid, which is very reactive.



6. Young's model does not account for the Mariner 5 anomalies at  $402^\circ K$  and  $371^\circ K$  (although the dry model does predict a cloud bottom of  $371^\circ K$ ).
7. Dr. Young would prefer to see measurements begin at  $200^\circ K$  ( $\sim 76$  km) but certainly at  $230^\circ K$  ( $\sim 68$  km).

A copy of Dr. Young's preprint is attached.

  
R. K. Edwards

  
L. J. Nolte

  
P. A. Robinson

Attachment -- A/N

GHER

25.0 INTERDEPARTMENTAL CORRESPONDENCE



TO: Distribution D  
ORG:

CC:

DATE: April 18, 1973  
REF. HS507-0534

SUBJECT: Meeting with Dr. A.L. Fymat

FROM: A. M. Lauletta, Jr.  
ORG. 44-23-00

BLDG. 376 MAIL STA. 11141  
EXT. 8-2479

On Friday, April 13, R.A. Park and myself met with Dr. Fymat and F. Vescelus of JPL. Dr. Fymat has proposed a Solar Flux and Atmospheric Absorption experiment for the Pioneer Venus Probe mission. Professor V. Soumi is the principal investigator and along with Dr. Fymat there were five other coinvestigators from France, University of Wisconsin and JPL, a rather formidable team.

Dr. Fymat primarily stressed the fact that in addition to the transport of solar flux this instrument will measure absorption of the Venus atmosphere.

I have a copy of the proposal in my office for a more detailed analysis and won't go into detail here.

The instrument uses four separate detectors, two looking up  $180^\circ$  apart and two looking down  $180^\circ$  apart. One set measures the direct energy coming down and going up, similar to a flat plate. The second set measures the total hemispherical energy in the upper half, i.e. from parallel to the equator of the probe to that coming directly down, and the same for the lower hemisphere.

The experiment requires a spin rate of at least 5-10 rpm and derivation of the spin rate for data reduction, but not real time.

Each of the four detectors is independent; they do not require a common detector or fiber optics for transmission.

  
A. M. Lauletta, Jr.

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A-349